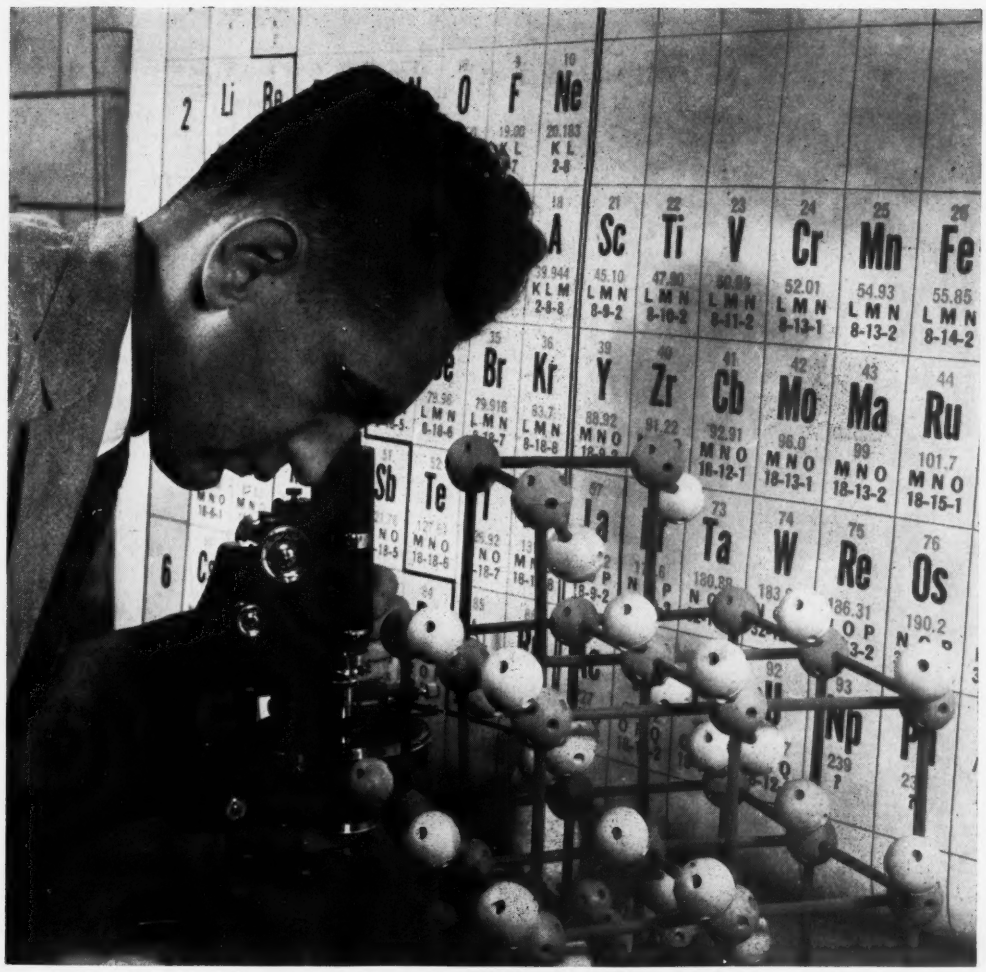
Vol. [illegible] No. 2 March-April, 1956

LUBRICATION ENGINEERING

RESEARCH APPLICATION EDUCATION MAINTENANCE

ASLE 11th Annual Meeting & Exhibit Issue



Examining Crystalline Structure Of A Catalyst

(Cover Story, p. 116)

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LUBRICATION ENGINEERING

RESEARCH APPLICATION EDUCATION MAINTENANCE

Vol. 12, No. 2 March-April, 1956

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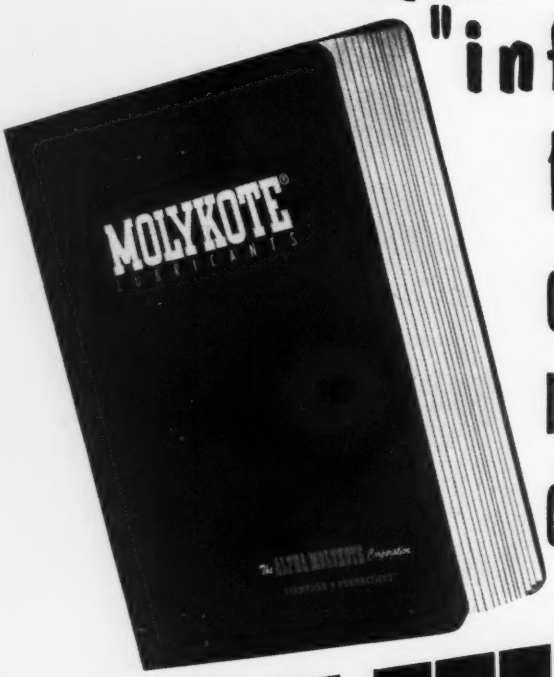

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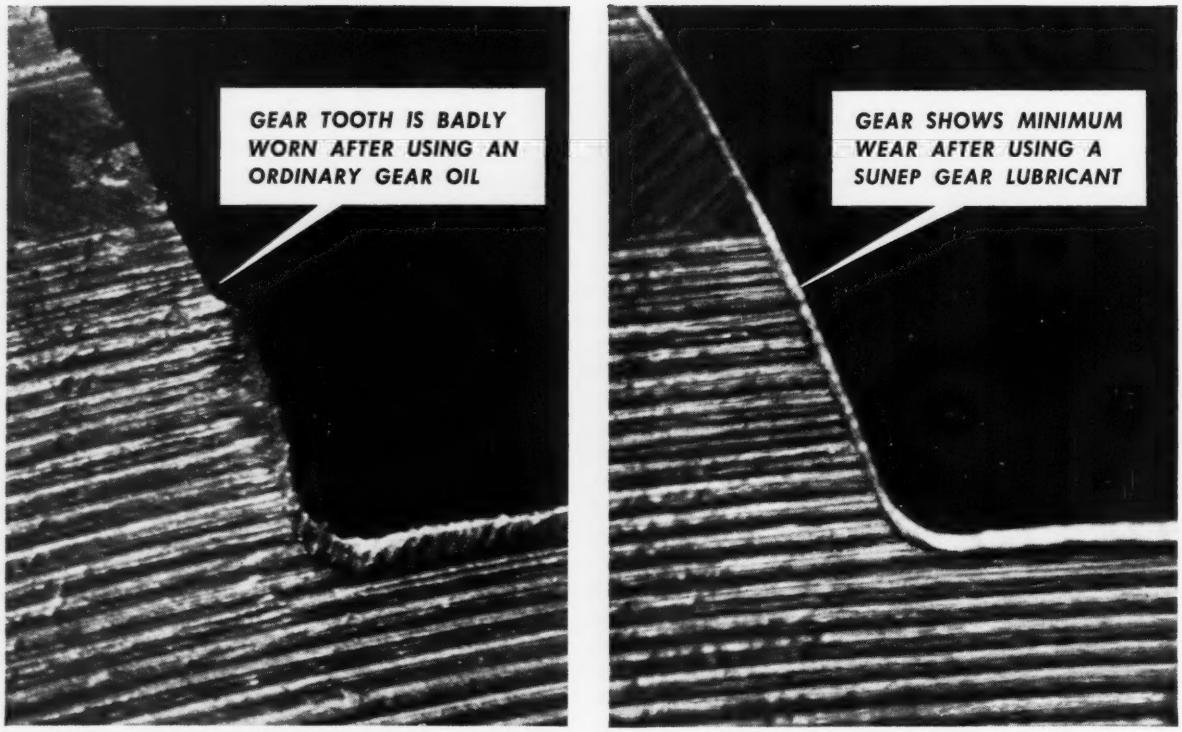

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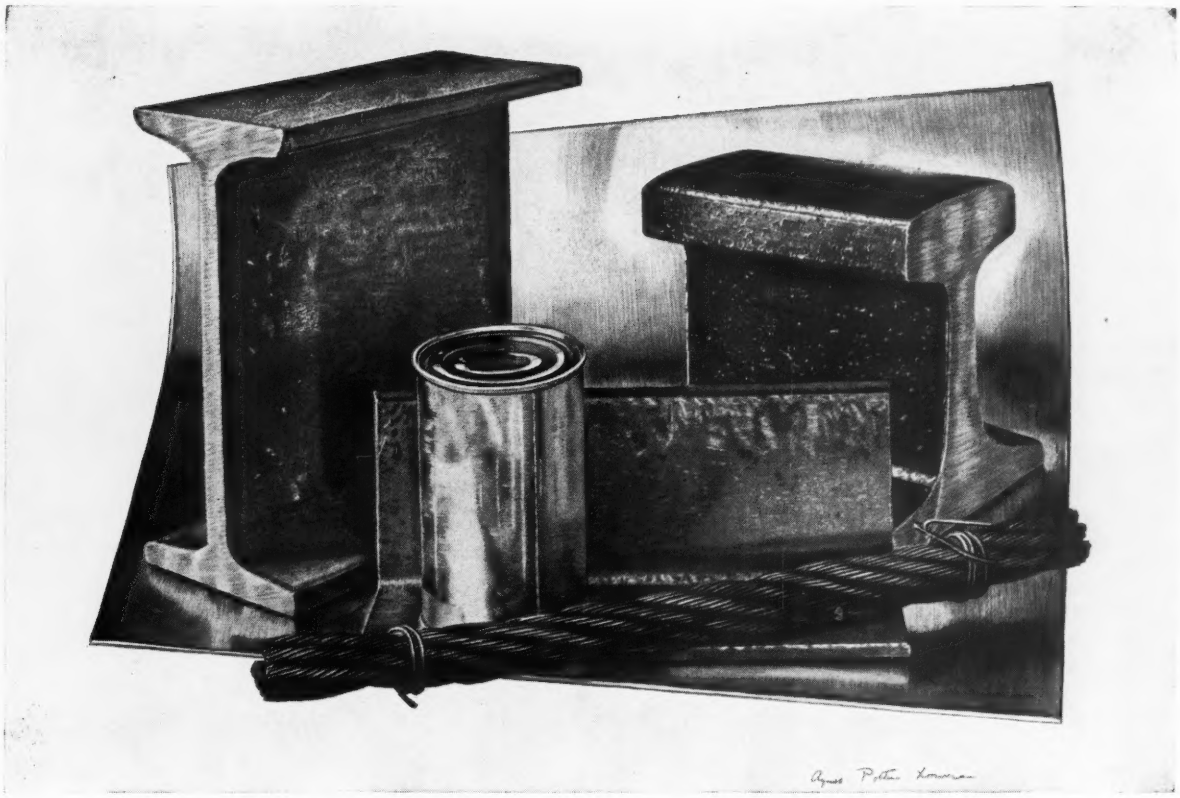

"Steel from the Furnaces." Agnes Potter Lowrie depicts some of the basic steel products which provide the sinews of American industry. The I-beam, key piece in building construction. The angle iron. Wire rope. Railway track to carry the carriers of industry. The can, universal container for foods and liquids. And in the background, sheet steel, gleaming symbol of strength and durability.

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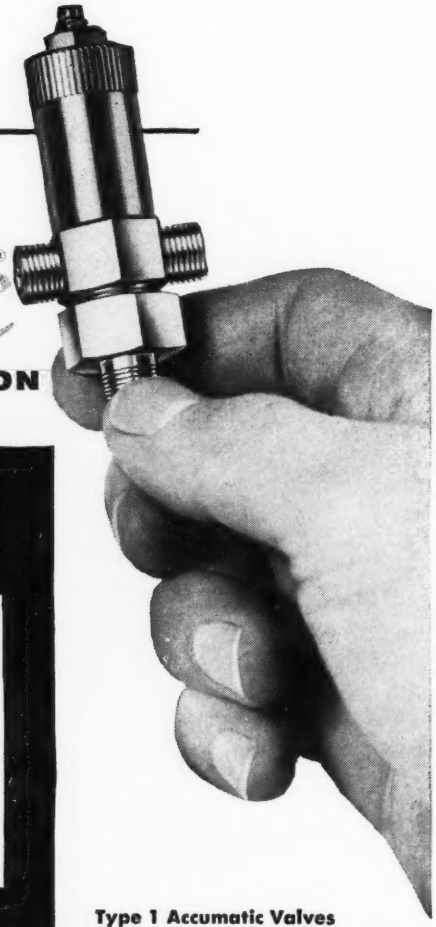

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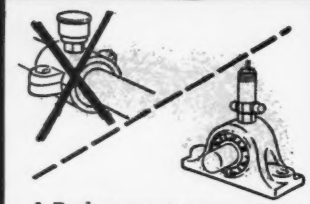
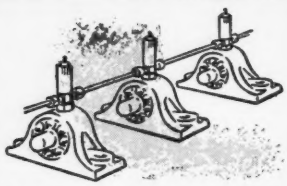
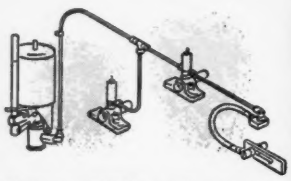


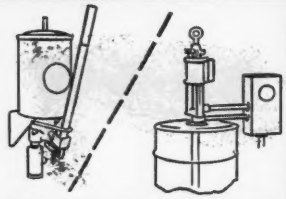
1. Replace grease cups or grease fittings with Accumatic fittings. (Available in same thread sizes as grease fittings, cups.)



2. Connect Accumatic fittings with copper tubing. (Alemite has tubing, clips and accessories for fast, neat installation.)



3. Connect sliding, rotary or oscillating parts into tubing system. (Flexible hose and swivels available for moving parts.)



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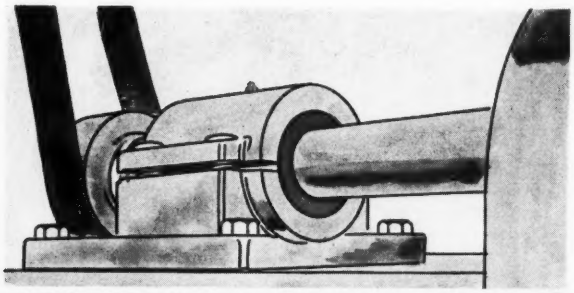

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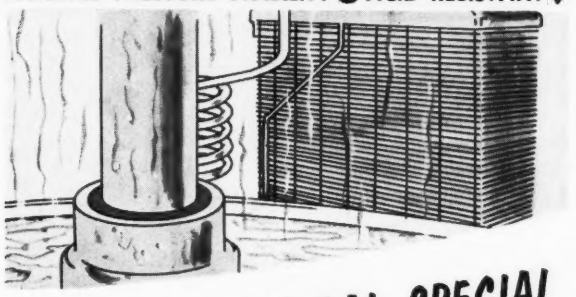

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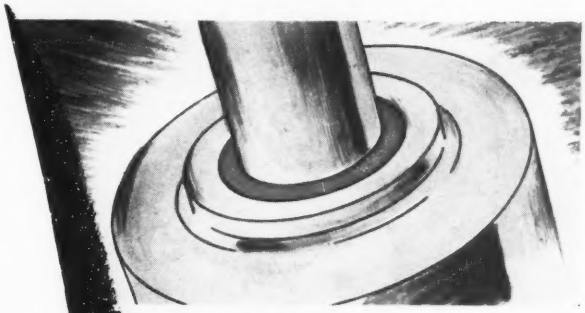

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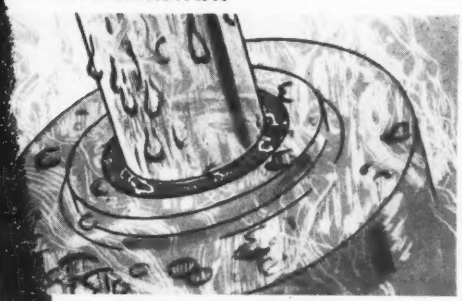

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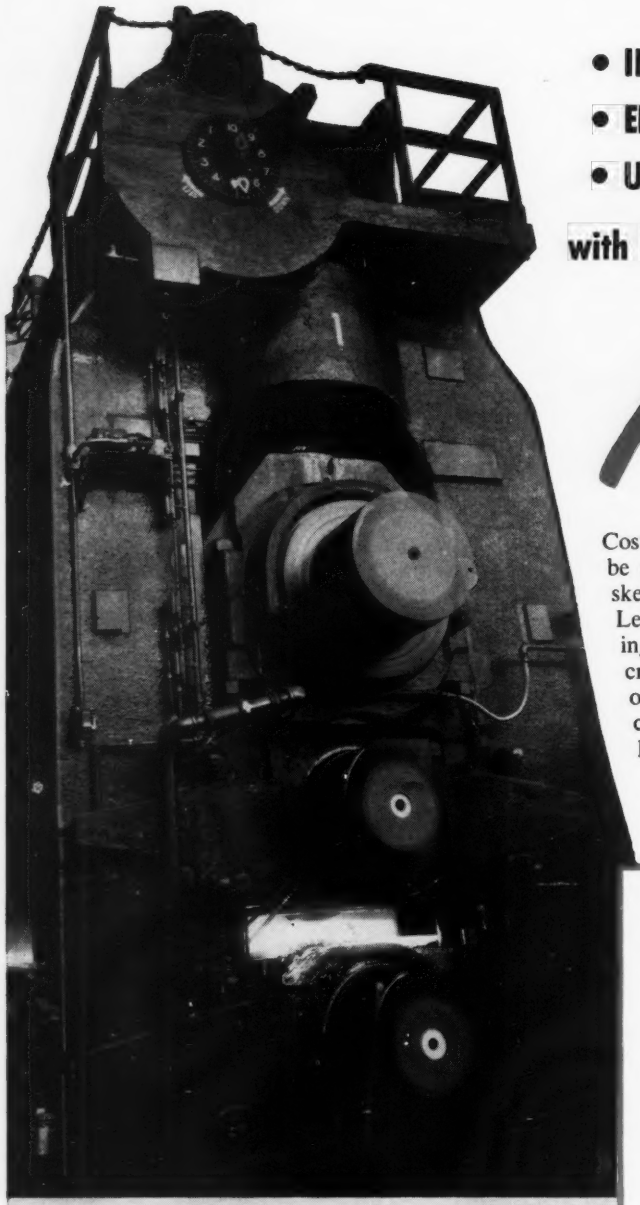

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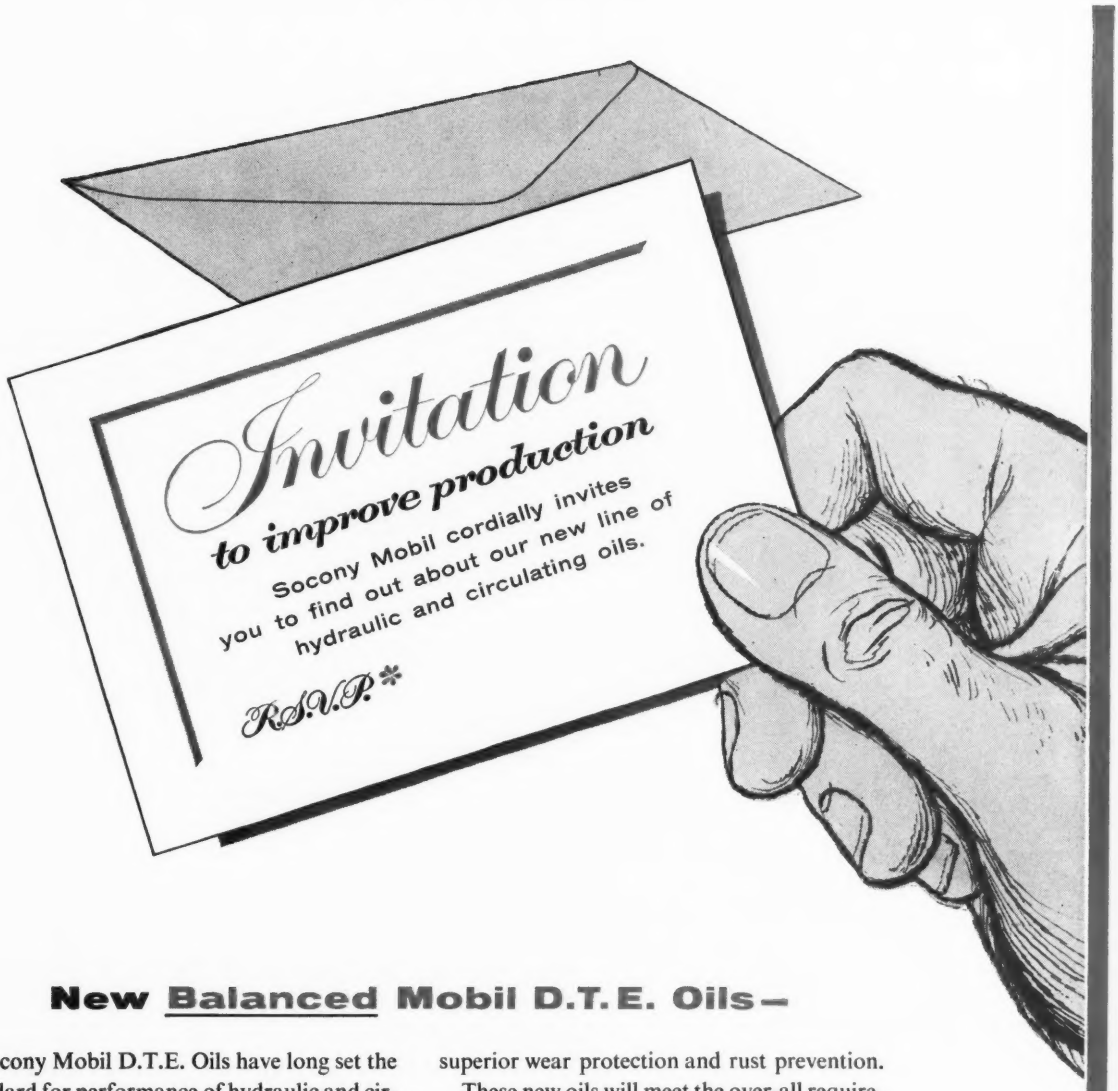

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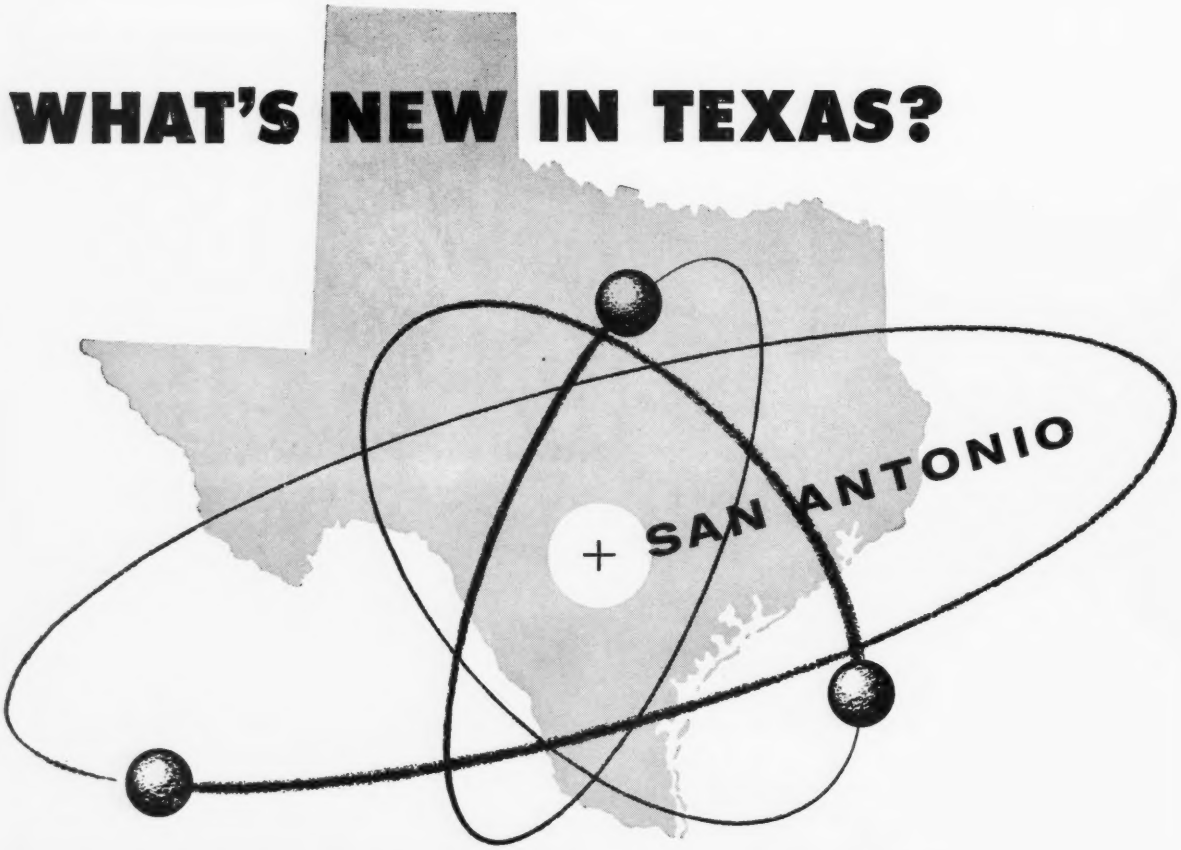

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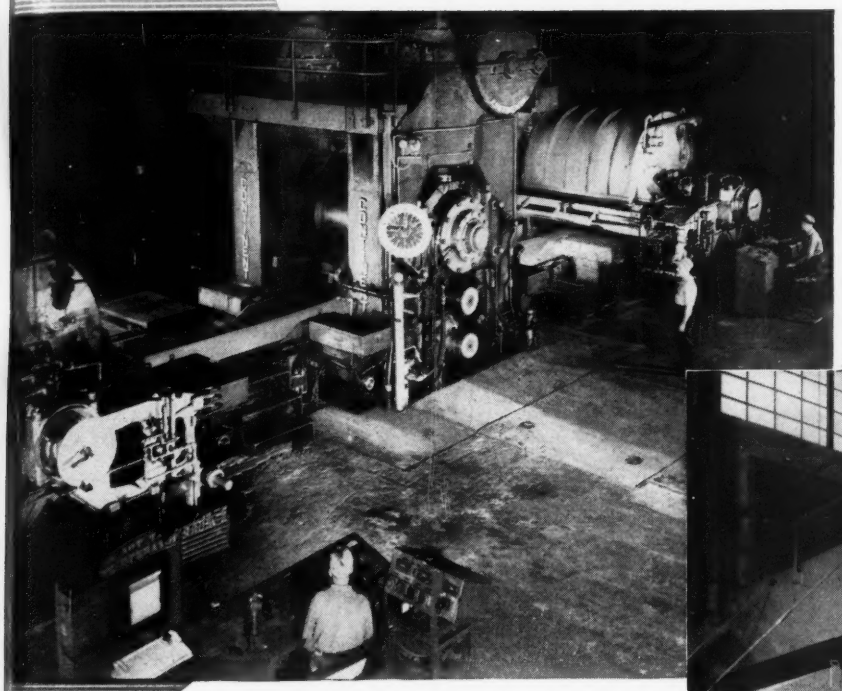

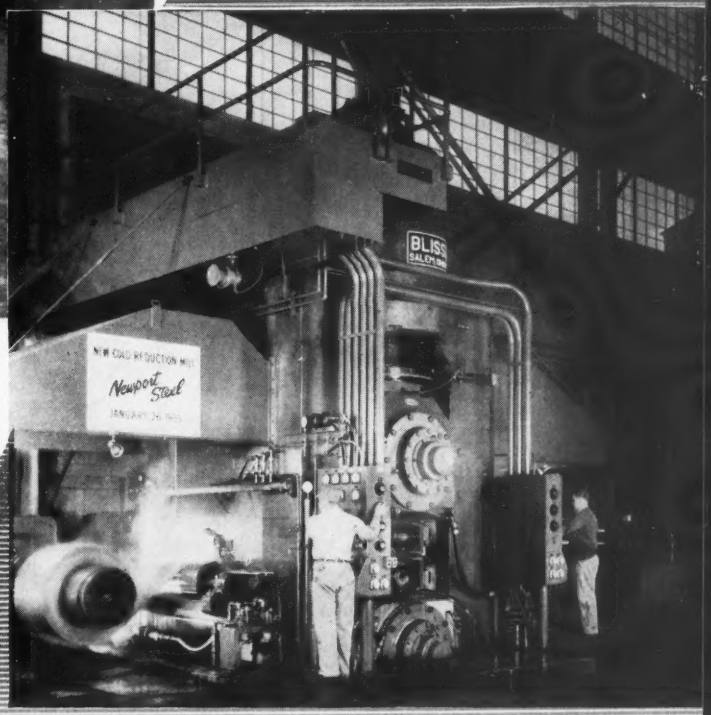

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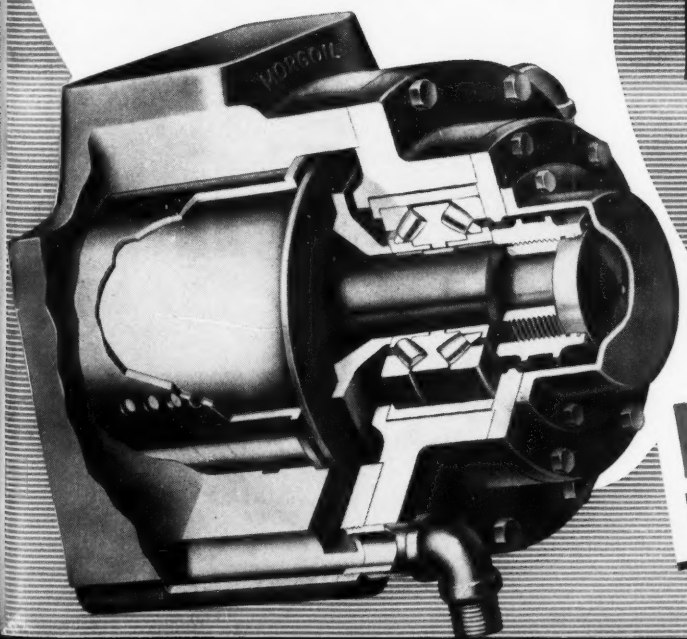

The recent modernization at NEWPORT STEEL CORPORATION, Newport, Kentucky, features a four-high reversing hot mill with Steckel-type furnaces and a four-high cold reduction mill. BOTH mills are equipped with MORGOIL bearings for maximum efficiency.

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There is only one **INLUCITE 21.**

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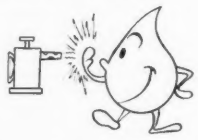
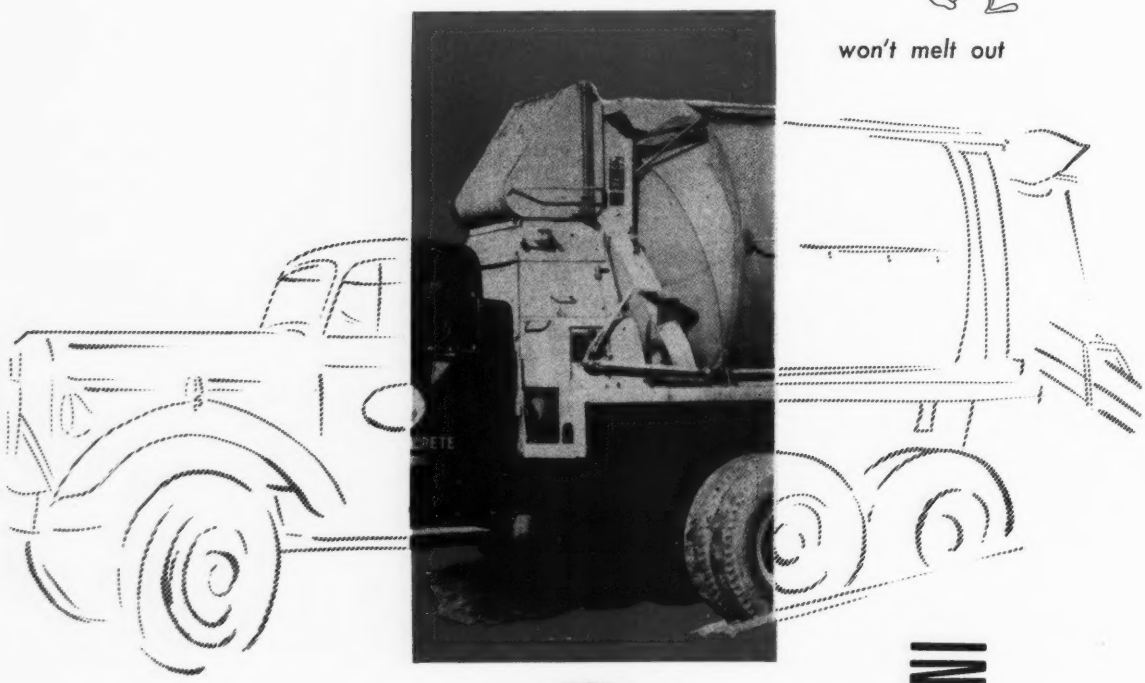
won't squeeze out



won't melt out



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A Convenient Measurement Of Friction Coefficient, by H. E. Mahncke (Rayonier, Inc., Whippany, New Jersey; formerly with Westinghouse Research Laboratories where this experiment was conducted.).

In studying lubricants, it is quite often desirable to determine coefficients of friction of lubricated surfaces. These data are of considerable value for comparative purposes even though they may have little absolute significance. In carrying out such measurements, the test method is the more useful the more it satisfies the two criteria of convenience:

(1) The measurement should be simple and easy to carry out.

(2) The test pieces should be easily procured and prepared for the test.

We have found that a friction pendulum meets these requirements very well and can be used for a wide variety of experiments. While various types of pendulums have been described for sliding[1, 2, 3] and rolling contact,[4] our experience has been limited to an instrument modified from the design of Kyropoulos and Shobert,[2] by the incorporation of a 4-ball contact as suggested by Muskat.[5] As shown in Fig. 1, the sliding contacts are effected between two ¾" balls clamped on the supporting frame and two clamped in the head of the pendulum. The lines connecting the centers of each pair of balls are at right angles to each other. An overall view is shown in Fig. 2. The pendulum is about 1 meter long. The weight can be adjusted as desired.

The measurement of friction is fairly simple. A clean set of balls is clamped in place and a final cleaning with solvents given. The test lubricant is applied with a swab and the pendulum set on the support. It is then displaced through a fixed angle, released, and the number of cycles through which it swings before coming to rest is observed. The coefficient of friction is calculated from the formula[2]: $f = k/n$ where f = coefficient of friction, n = number of cycles, k = a constant to be determined for each instrument. Under the best conditions (not always attainable) values are reproducible to ± 2%. This is ample for the detection of differences between lubricants. It is to be observed that we are dealing here with boundary friction, since the very high contact pressures effectively eliminate hydrodynamic effects. It should also be noted that the measured coefficient is a composite of the static and kinetic values.

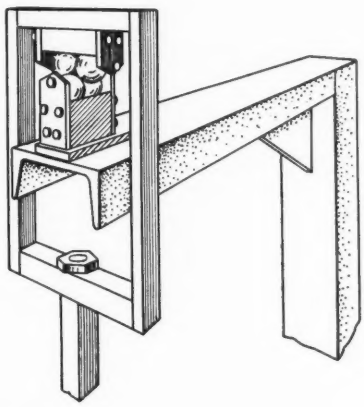


Fig. 1.

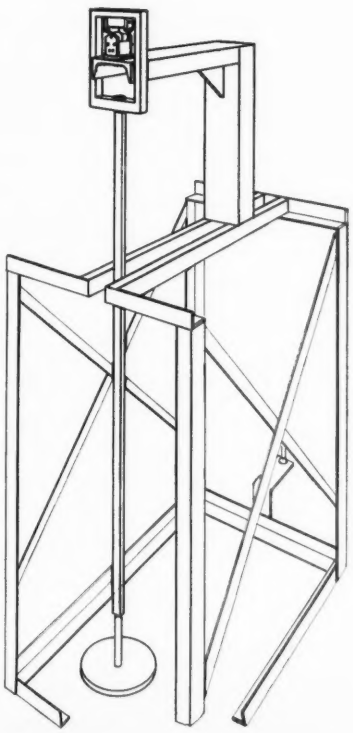


Fig. 2.

In the majority of cases, standard ¾" balls of various metals are easily obtained. We have used steel, stainless steel, carboloy, brass, bronze, aluminum, and tungsten carbides. If only smaller balls are available, the ball cavities may be filled with spacer bars to raise the ball center and allow contact to be made. If balls are not available in the desired material, a very satisfactory substitute is obtained by turning a cylinder ¾" diameter by ¾" long and finishing one end as a hemisphere with a ⅜" radius. This technique has proved particularly useful in the study of polymers and electroplated surfaces.

As might be expected, the instrument is also useful for making controlled wear studies by observing the development of the wear scars between successive tests.

BIBLIOGRAPHY

(1) T. E. Stanton. The Engineer, Vol. 135, 1923, p. 678. See also "Lubrication & Lubricants," p. 423, by L. Archbutt & R. M. Deeley; J. B. Lippincott & Co., 1927.

(2) S. Kyropoulos & E. I. Shobert. Rev. Sci. Inst., Vol 8, 1937, p. 151.

(3) G. E. Barker, et al. ASTM Bull. No. 139, March 1946, p. 25.

(4) G. A. Tomlinson, Phil. Mag., Vol. 7, 1929, p. 905.

(5) M. Muskat. Private communication, Gulf Research & Development Corp., 1943.

Coming Events

APRIL, 16-18, American Institute of Electrical Engineers (The Great Lakes District Meeting), Fort Wayne, Ind.

MAY, 3-9, American Foundrymen's Society, Atlantic City, N. J.

7-9, 2nd Italian Meeting on Chemistry & Technology of Fats, Milan, Italy.

9-11, American Welding Society (4th Annual Meeting & Exhibit), Memorial Auditorium, Buffalo, N. Y.

14-17, 1st Annual Design Engineering Show & Conference, Convention Hall, Philadelphia, Pa.

23-25, American Management Association (General Management Conference), Roosevelt Hotel, N. Y. C.

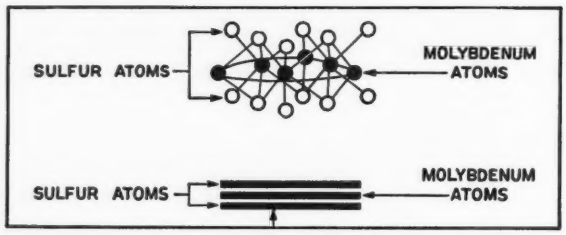
Effective lubrication of torsion suspension bushings of heavy duty trailers has been a maintenance problem with many truckers. The bushing at the left was removed still in good condition after 160,000 miles of service. This bushing was lubricated with a chassis grease containing Moly-Sulfide additive. The bushing at the right, lubricated with ordinary chassis grease, needed replacement after 35,000 miles of service.

How Moly-Sulfide additives EXTEND EFFECTIVE LUBRICATION

Why Moly-Sulfide additives are used in lubricants by trucking fleet operators, railroads, aircraft and automotive manufacturers, oil well drillers and steel mills.

Moly-Sulfide has six characteristics which make it an ideal lubricant additive wherever mechanical action wipes or shears off the hydrodynamic film.

1. Because of its affinity for metals, Moly-Sulfide readily forms a film on metal surfaces.
2. Moly-Sulfide has a low coefficient of friction.
3. It has a high factor of durability.
4. Moly-Sulfide has a thermal stability of −100°F. to +750°F.
5. It has a high chemical resistance to acids, alkalis and water.
6. It withstands high pressures, having a low shear strength and a high film strength.

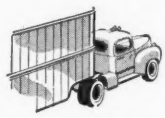


Above, structural diagram of the Moly-Sulfide molecule. Below is a functional illustration of the laminar structure. Each lamina is composed of a layer of molybdenum atoms with a layer of sulfur atoms on each side.

What is Moly-Sulfide and how does it function in lubrication?

Mined in Colorado as molybdenite, purified Moly-Sulfide is a lead-grey material. It has a laminar molecular structure, with the Moly atoms sandwiched between layers of sulfur. (See illustration.) The sulfur atoms have an affinity for metal and

bond readily to metal surfaces, giving the film a *low shear strength*. This affinity is caused by a strong intermolecular bond between sulfur and metal. The lubrication results from the easy slippage of sulfur-to-sulfur atoms. As an additive to lubricants, the *Moly-Sulfide will readily form a film and when a grease or oil film is wiped away or sheared off, the Moly-Sulfide film sustains lubrication until a petroleum film reforms.*



Truck and passenger car builders and operators are making wide use of Moly-Sulfide greases for difficult lubrication jobs.

Lubricants containing Moly-Sulfide additive have over 30 established uses in the automotive, aircraft, railroad, oil drilling and steel industries.

Since Abraham Lincoln's time, railroads have been faced with a serious, recurring, *expensive* problem: hotboxes. Right now more than 14 million journal bearings are carrying heavy loads at high speeds on American railroads. These railroads have to deal with an average of 183,000 hotboxes a year at a cost of some $90,000,000.

Initial field tests by at least three leading railroads have shown hotboxes can be reduced materially by the use of grease containing Moly-Sulfide. A way has been devised to apply greases containing Moly-Sulfide on the journals of railroad equipment. This application is supplemental to the oil waste system and as a result the Moly-Sulfide films that are formed sustain lubrication until the oil film is reestablished.

American automobile and truck manufacturers and their customers are now using lubricants containing Moly-Sulfide additive in at least 14 different applications. These include chassis points, ball joint suspensions, torsion suspension assemblies, fifth wheels, shackle bolts, king pins, valve stems, automatic window mechanisms, wind-shield wiper mechanisms, seat adjusters, drive shaft splines.

In aircraft, Moly-Sulfide is added to aircraft greases. In jet engines under exacting conditions of temperature and pressure it is used on turbine shaft, splines and gear reduction units.

In other industries, Moly-Sulfide is being used in lubrication jobs which formerly presented serious difficulties. A Florida cement plant is using gear compound containing Moly-Sulfide to lubricate rack gears and a Michigan manufacturer uses Moly-Sulfide as an additive to drawing compounds for drawing stainless steel hub caps. In New York a baker of crackers and cookies is using Moly-Sulfide grease for lubrication of oven chains which must operate at high temperatures. In Louisiana an oil well drilling contractor is using Moly-Sulfide additive in tool joint compounds. He reports that disjointing when drilling below 15,000 feet is no problem now: no galling, welding or stripped threads.

Aircraft manufacturers are using Moly-Sulfide greases on many types of ball and joint suspension lubrication.

Oil well drilling contractors are using Moly-Sulfide additives to tool joint compounds.

Lubrication engineers are offered information and help in evaluating the use of Moly-Sulfide as an additive to lubricants by the Climax Molybdenum Co.

Currently Moly-Sulfide is being investigated by many petroleum research laboratories and lubricant users. They are interested in studying, under practical working conditions, the ability of Moly-Sulfide to increase effective lubrication.

If insuring effective lubrication is a problem facing your company, Moly-Sulfide additives may be a solution. Climax Molybdenum Company is the principal source of this product. If you need authoritative information, please get in touch with us and we will be pleased to send you literature on Moly-Sulfide and the sources of supply for experimental lubricants containing Moly-Sulfide.

DEPARTMENT 38
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500 Fifth Avenue, New York 36, N. Y.

Please send me the following:

Literature
1. "Moly-Sulfide, Lubricant Additive" ☐
2. "Moly-Sulfide in Chassis Grease" ☐
3. "Moly-Sulfide Specification and Properties" ☐

List of Sources for
1. Railroad Greases ☐
2. Chassis Greases ☐

Sample — One-ounce tube of Moly-Sulfide ☐

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Company .....

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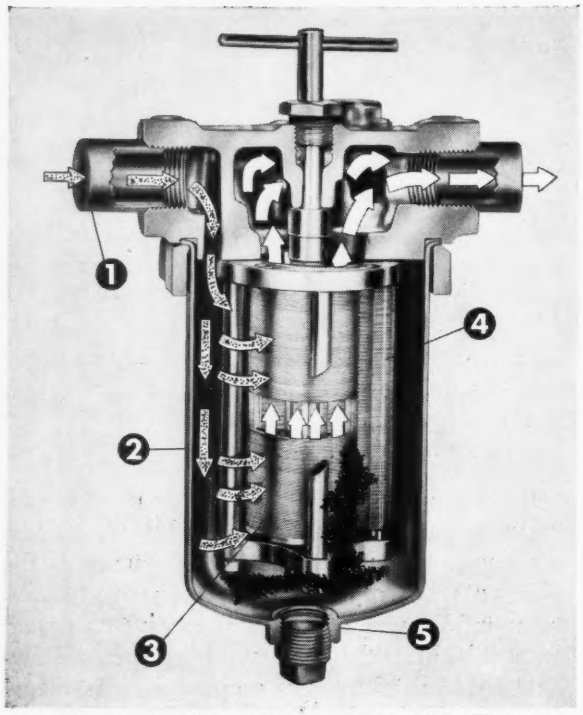
NOW! 40-micron, self-cleaning filter
It's the new Cuno SUPER Auto-Klean



HOW IT WORKS. Dirty oil enters inlet (1) at left, fills housing (2) and flows through metal edge-type filter (3). Clean oil rises through center of filter, leaves at right. Dirt combed out by cleaner blades (4) is removed through drain (5).

Cuno's new SUPER Auto-Klean is the first practical, compact micronic filter for lubricating oil, hydraulic fluid, coolant, fuel, and other industrial fluids.

Many times smaller than other micronic filters of equal capacity, Cuno's new SUPER Auto-Klean filter now makes possible economical, micronic filtration at high flow rates and eliminates the need for replacement cartridges in most cases. Here's what it offers:

1. Full-flow 40-micron filtration with a self-cleaning filter. Positive protection against particles larger than 40 microns (actually 0.0015 in.). All-metal filter can't rupture or channel.

2. Easy cleaning. Just turn the handle—by hand or continuously with motor drive. No interruptions for cleaning.

3. No cartridge changes. Ends operating costs if you've been using cartridge filters.

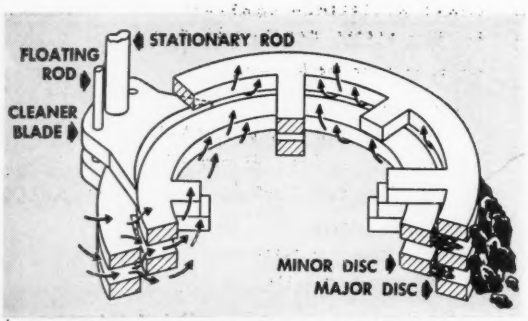
4. Low pressure drop, no pressure drop build-up. An 8" by 2¼" SUPER Auto-Klean filters 30 gpm of 200 SSU oil with only 3 psi pressure drop—up to 75% more with slightly higher pressure.

5. High capacity in a small package. Many times smaller than replaceable-cartridge type filters of equal capacity, it saves with lower initial costs, lower installation costs.

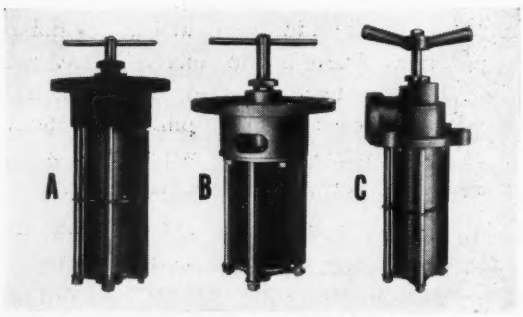
6. Easy to build into new equipment. Available for line-type housings *(left)* or incorporation in sump or reservoir *(below.)* Works in any position.

7. Easy to install in old equipment. Fits existing Auto-Klean housings. You can easily replace most 2¼" diameter elements with SUPER Auto-Klean for finer filtration.

Write today for complete technical data on the new SUPER Auto-Klean for your new or existing equipment. Ask for Catalog No. SAK-057. Cuno Engineering Corporation, 13-3 South Vine Street, Meriden, Connecticut. 5.9



FILTER ELEMENT consists of stacked major and minor discs and cleaner blade bearing against minor discs. Small arrows show flow. Short restrictions between minor and major discs stop 40-micron particles but allow high flow rate.



FILTERS FOR INTERNAL PIPING *(A and B above)* allow streamlined design plus the best infiltration. Flange mounting with external outlet *(C above)* and line-type *(large cutaway above left)* are just a few of many other possibilities.

CUNO **ENGINEERED FILTRATION**

Removes More Sizes of Solids From More Kinds of Fluids

AUTO-KLEAN (edge-type) • MICRO-KLEAN (fibre cartridge) • FLO-KLEAN (wire-wound) • PORO-KLEAN (porous metal)

Lube Lines

by A. F. Brewer*

PURCHASING LUBRICATION. Buying any type of product according to certain reasonable specifications can have merit and often reacts to the benefit of the purchaser. Obviously the specifications should relate to quality; it may or may not comprise physical tests. Where lubricants are concerned, it is important to remember that in addition to buying products we also are buying results—lubrication.

In the purchase of petroleum products, a specification usually indicates physical tests which denotes the physical nature of the oil or grease. In addition, according to the intended use, the specification can be broadened to suggest the type of additive (if an additive is considered necessary) or the soap base in a grease.

Such a specification, however, can be a two-edged sword, if it is too restrictive as to limits or if it attempts to cover methods of refining. Then it may limit the lubricant manufacturer in his ability to make use of the most modern methods of refinery processing. This is stated advisedly, on the presumption that too many purchase specifications become out-of-date very rapidly due to the progress which is continually being made by petroleum technology. What is modern today can very easily become obsolete tomorrow. This has been particularly true during the past few years, as the study of synthetic lubricant components, anti-oxidants, detergents, and rust preventives virtually revolutionized the science of lubrication. This research was accelerated by war-time demands for better heat- and cold-resistant lubricants, for products which would assure bearing protection at speeds approaching 100,000 rpm, for cutting oils and coolants which would keep metal-cutting and grinding tools in service longer.

Lubrication Performance, the Criterion. Selection and subsequent purchase of lubricants has a direct effect upon the performance of the machinery to be lubricated. It all depends upon the extent to which lubrication performance is considered. Lubrication performance is a measure of the results obtained from the application of lubricants. It can readily be converted into a monetary value by recording costs of lubricants, repair parts, labor for parts replacement, and production losses due to machinery down time, if these repairs are traced to faulty lubrication.

Purchase of premium lubricants will not necessarily assure more dependable lubrication performance; it may, if the characteristics of these lubricants are suited to the operating conditions. Too often, however, a premium grade lubricant may be used to offset a structural defect such as misalignment, or an operating condition which should be corrected instead.

Purchase of lubricants by specification can be equally misleading. Simply because a buyer stipulates a set of physical tests to his lubricant supplier is no assurance that the former is going to get the lubricant best suited to his operating conditions. Some red oils, pale oils, or filtered products can be refined to approximately the same range of physical tests according to their viscosity, yet their ultimate stability in service will vary widely. For average service they might all give good lubrication, but if temperature should change abnormally or if unduly high temperatures should increase the oxidation conditions, the assurance of dependable lubrication would be reduced.

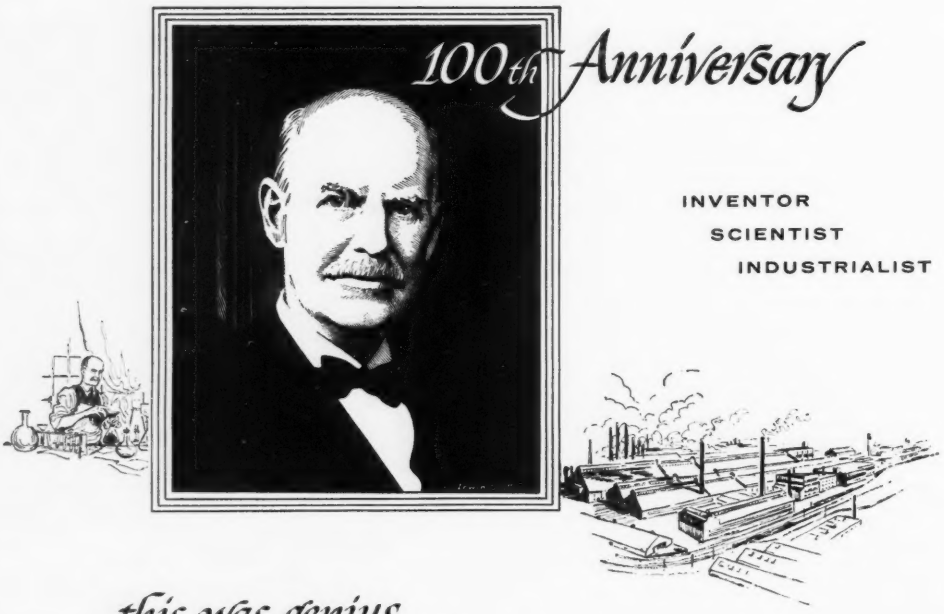
On the other hand, if a purchase specification should require an anti-oxidant additive and the oil or grease bought under this specification were to be used for miscellaneous lubrication where such an additive is not needed, the overall cost of lubrication would be increased. It is all very well to say "do not use premium-additive lubricants promiscuously," but there always is a desire among operators to reduce the number of lubricants in stock. When there is doubt as to which extreme to approach, the advice of a competent lubrication engineer is a better factor of safety than an arbitrary specification.

Features of machine design, of course, are always important. The best interests of the plant will be served if these are outlined by the operating or engineering people and furnished to the purchasing department. If the latter purchases lubricants on a typical test basis in accordance with the design requirements of the plant machinery, better lubricant performance usually can be expected. For example, some gear cases or bearing housings may have to be built with no provision for draining or removing the lubricant without considerable disassembly. Durability or chemical stability of the lubricant for such service is more important than conformation with a set of test limitations which might have little or no bearing on the service. A light-consistency, non-channeling grease containing a suitable anti-oxidant would probably be best, and it could be of mixed-base (sodium-calcium) or lithium soap. To place a base restriction in a specification for such service would not affect the subsequent performance.

MEMBRANE-TYPE COMPRESSOR. "Refrigerating Engineering" for January 1956 contains an interesting discussion of the membrane-type compressor as developed in France. The basic principle of this device involves the elastic deformation of a circular membrane to cause alternate suction and discharge of the fluid or gas being handled. A feature of this compressor, which makes it well suited to refrigeration and chemical service, is the fact that there is no lubricating oil pollution of the fluid or gas conveyed by the oscillations of the membrane. Meanwhile, oil-fog lubrication of the moving parts of the reciprocating oil pump, which forms the major part of the machine, is brought about by

(Continued on p. 157)

*Consultant, and Author of "Basic Lubrication Practice."



this was genius . . .

EDWARD GOODRICH ACHESON

Yes, this was genius.

Thomas A. Edison knew it. In paying tribute upon the occasion of Doctor Acheson's passing, he said "... as a former associate I know the world loses a great genius."

Leo Hendrik Baekeland knew it. He remembered him "as a man who combined a most fertile brain with great strength of conviction."

Walter B. Pitkin knew it. This famous psychologist said "As he created his place in our civilization so does that place pass with him. None shall fill it."

And the press knew it. They used in their editorials such phrases as "world's acclaim of a genius," "one of the geniuses of his time," and "the loss of an inventive genius."

But what makes genius?

Employing a mixture of carbon, sand, salt, and sawdust in a simple but effective electric furnace, made up of a few strands of wire, a carbon rod, and a plumber's bowl, Edward Goodrich Acheson was able to bring into being a mass of scintillating crystals rivaling many gems in splendor and almost matching the diamond in hardness. These highly abrasive crystals he crushed and made into grinding wheels, and these wheels, in turn, were used to shape metals and make machines. Called "Carborundum" by Acheson and silicon carbide by the chemist, this new material did its job so well that it is credited with making possible today the mass production of automobiles, tractors, and countless other mechanisms.

Possibly silicon carbide could be made better—harder or sharper. To this end Acheson subjected silicon carbide to higher temperatures for longer periods; what he obtained was not a harder substance but, instead, one of the softest—pure graphite. The extreme conditions to which he had exposed his jewels of industry brought about their disintegration, the silicon passing off as vapor and the carbon remaining as a soft, unctuous residue. Manufactured graphite, destined to be of far-reaching importance, became another of Acheson's contributions to industry.

Unquenchable curiosity, coupled with the indomitable spirit that was his, led him to uncover means of preparing this new product of the electric furnace in the form of plates and cylinders. Put to work as electrodes, these soon revolutionized electrochemical and electrometallurgical operations. Acheson had now made commercially feasible the production of new families of chemicals and laid the groundwork for the present efficient manufacture of steel and alloys.

During Acheson's painstaking efforts to produce graphite crucibles he experimented with many clays for use as binding agents—and he learned much about them—so much in fact that he was able to explain why the ancient Egyptians used straw in their brick making and what caused the formation of the deltas of the Nile and Mississippi. Most important, he discovered a method of rendering graphite colloidal.

Colloidal graphite in modern industry plays a role that is varied and complex, its unique properties finding utility in such dissimilar fields as lubrication, electronics, metalworking, and lithography, to name a few. The techniques originated by Acheson for colloidally dispersing graphite are being applied to other solids including carbon blacks, pigments, and minerals.

To those of us in the companies identified with Doctor Acheson, his perseverance and achievement are an inspiration. We are proud to offer this tribute to his genius on the 100th anniversary of his birth.

Acheson Industries, Inc.

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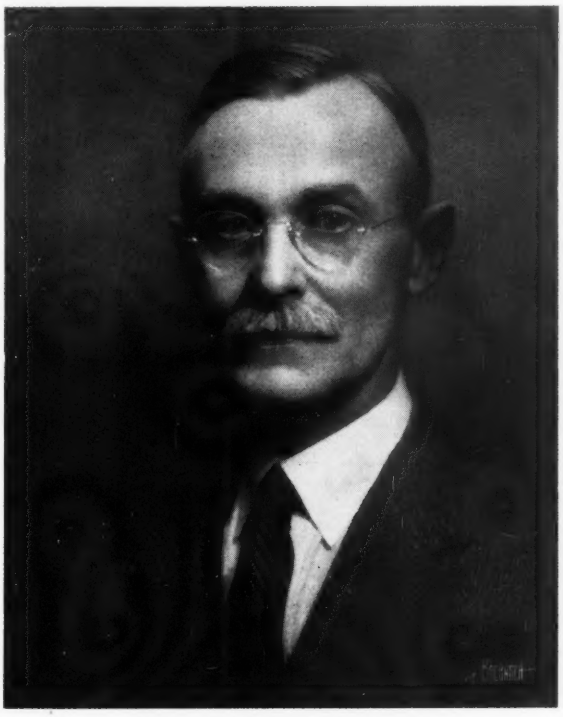
ACHESON COLLOIDS LIMITED
LONDON, ENGLAND

Men of Lubrication

by F. R. Archibald

ARTHUR E. NORTON. Arthur Edwin Norton was born in Portland, Maine, in 1877. The Nortons were seafaring people, his grandfather and several of his great uncles being captains of ocean going sailing ships. His father did not, however, follow the sea, but owned and ran a grocery store in Portland. His early education was obtained at Portland High School, and showed him to be a serious student. At school he showed the quality of leadership, and he was well liked. Upon his graduation from high school in 1896, he received a medal for scholarship. Norton's first introduction to engineering work was obtained in a night class in mechanical drawing given by the Charitable Mechanics Association.

Norton graduated from Brown University in Mechanical Engineering in 1900. He had enrolled at Brown in the Ph.B course which was largely elective. He must have decided to take mechanical drawing, for he met Professor (then an instructor) Kenerson who seems to have influenced him in his decision to take up Mechanical Engineering. During the course of his college career, one of his summer jobs was on the Back Bay Station of the New York, New Haven, and Hartford Railway Co. Norton assisted in the design of the station.



Arthur E. Norton, 1877-1940

Following his graduation from Brown, Norton went to Drexel Institute in Philadelphia for a year as an instructor in mechanical drawing. The following year he got an appointment as instructor in Mechanical Engineering at the Lawrence Scientific School, Harvard University, where he spent, virtually, the rest of his life. In 1910 he became Assistant Professor, and in 1920 Associate Professor. In 1931 he was appointed Professor of Applied Mechanics, the post he held at the time of his sudden death in 1940.

As an instructor and Assistant Professor, Norton taught courses in mechanical drawing, mechanism, and machine design. His quick grasp of principles is well illustrated by a reminiscence of Professor Kenerson: Norton was required to teach gear theory in the course on mechanism, a subject in which he had had no previous training. Professor Kenerson, at his request, gave him a one-hour discussion of the theory of gears. He required no further help. He was a devoted teacher, always accessible, sympathetic and ungrudging of his time to the students.

In 1915 Norton became interested in power plant engineering and, as a consequence, he was associated with James J. Storrow on coal conservation during the first world war as an engineer in the U. S. Fuel Administration. Later he made power plant studies for state hospitals in Maine and Massachusetts. During this period he invented a booster power plant for railway freight locomotives. The problems associated with railroad car brake shoes and journal bearings, with which he came in contact at this time, led him to the study of lubrication.

An interesting comment on Norton's activities following the world war is provided in a Minute of the Faculty of Engineering, Harvard University, prepared by colleagues a short time after his death. "A new era opened for Norton in the twenties. At this time a renascence was taking place in the field of applied mechanics, originating chiefly in the aerodynamic researches of Prandtl and his group at Göttingen. The new aerodynamics was soon generalized as fluid mechanics, and began to expand the scope of studies which had hitherto served the engineer under the label of 'Hydraulics.' At the same time, the demands of the growing art of the aeronautical engineer and other parallel developments brought a new urgency to the study of vibration, to the analysis of the strength of thin-walled structures, and to other imperfectly understood matters in the mechanics of solids. In this country the influence of Timoshenko was profound, both in the development of the theory and in the stimulation of a considerable group of young and able engineers. Norton responded notably to these developments. His interests, which had been principally in the constructional arts of the engineer, now became increasingly analytical and turned towards the science of the engineer. His instruction in machine design incorporated at once the new knowledge; his main interest became the application of the new fluid mechanics to the subject of

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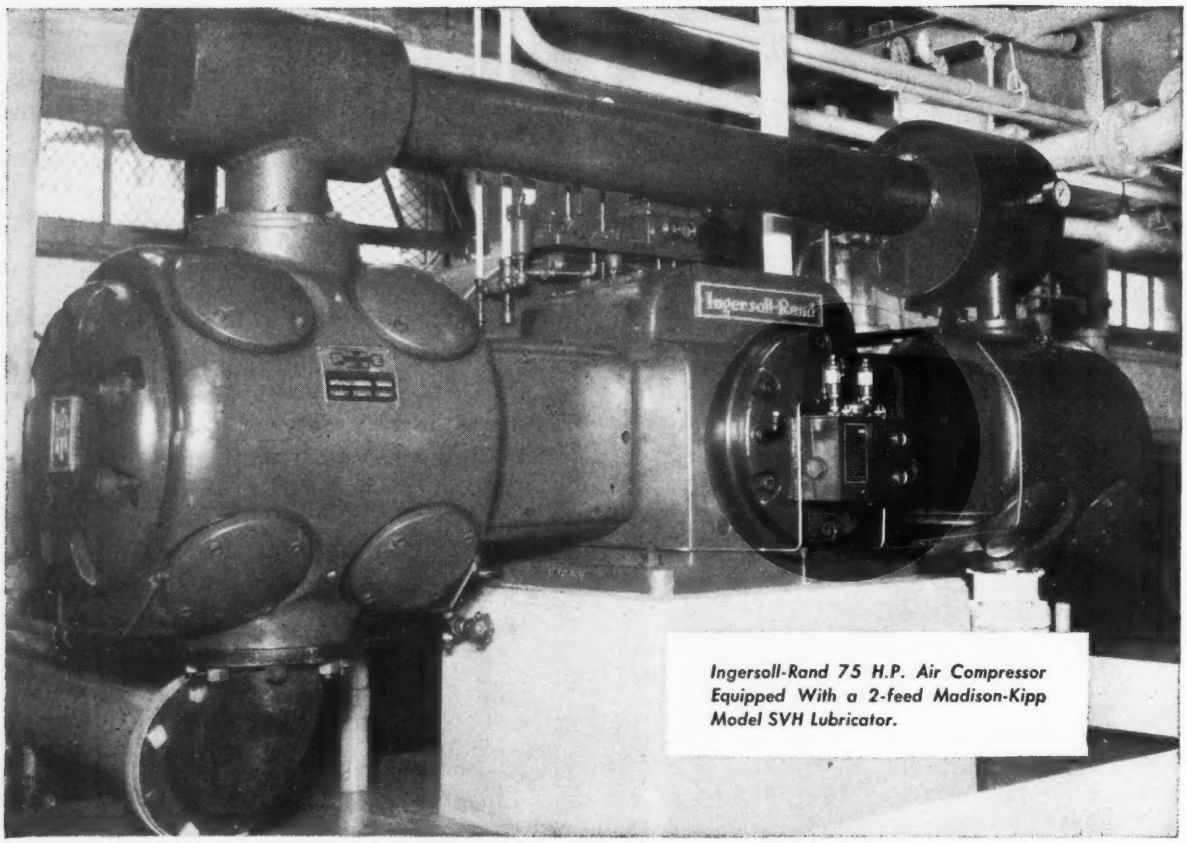

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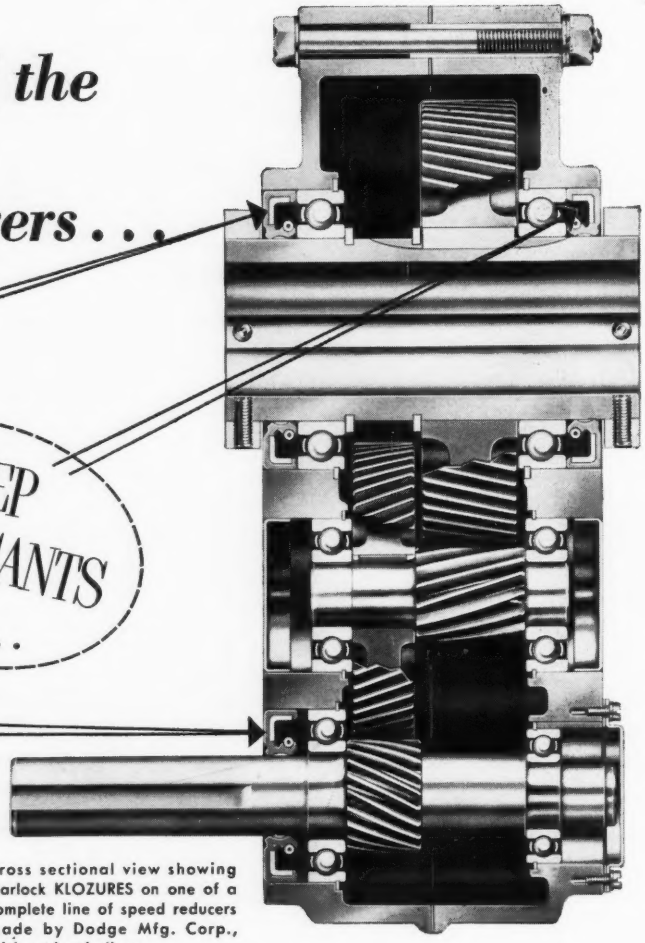

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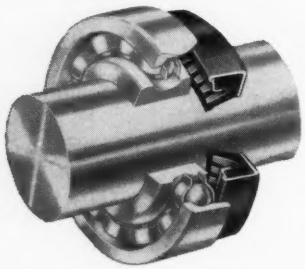

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Nature & Performance Of Some Inorganic Base Greases

by W. H. Peterson, J. B. Accinelli & A. Bondi*

Inorganic gelling agents are becoming increasingly important in grease preparation, thus a review of the potential advantages or disadvantages of these new products as industrial lubricants is timely. We shall endeavor in this paper (1) to survey the historical developments that led to the present greases, (2) to sketch the fundamental characteristics of the new gel systems, and (3) finally to illustrate the accomplishments to date by typical performance data.

Why a New Gelling Agent? To anyone familiar with current grease technology this question quite naturally presents itself, since the best soap type multipurpose greases have very few shortcomings. If the emphasis is on extremes in high and low temperature service, then only combinations of synthetic lubricating fluids with some new gelling agents will be useful. However, such solutions to provide multipurpose greases are economically unattractive, and we do not propose to discuss such specialty products, since they are rarely of interest in industrial lubrication. Why then go to radically different gelling agents?

The answer is that through relatively small improvements the usefulness of a multipurpose grease can be greatly extended. In a plant, the point most difficult to lubricate generally determines the minimum quality expected of multipurpose lubricant. Thus the influence of such lubrication points upon multipurpose grease specifications is out of all proportion relative to their number. Fig. 1 illustrates schematically the possible effect of raising the temperature ceiling (for long term performance) on the fraction of plants which can be serviced by a single multipurpose grease. The same is true for better lubrication under water wet conditions. Such an extension of the usefulness of a multipurpose grease justifies, in our opinion, a considerable effort.

History of Inorganic Gelling Agents for Organic Fluids. Of the two principal gel agents, silica and clay, silica was the first to be proposed for grease making. Thomas Graham, the founder of colloid chemistry, showed how silica gel could be transferred from its aqueous environment into organic liquids where it served as a gelling agent.[2] The application of this idea to the manufacture of lubricating greases had to wait about 60 years, when in 1927 German investigators proposed the use of silica gel for grease making, using, incidentally, Graham's original procedure of miscible solvent transfer for their preparations.[8] The use of silica gels, of various types, for grease manufacture has since been claimed by a number of inventors.[6-11] In the case of clay, only a short time interval elapsed between the discovery of the fundamentals of clay oleogel preparation and their application to lubricant manufacture.[1, 5] Other materials such as calcium carbonate, calcium silicate, and magnesium silicate have also been proposed but not developed commercially as grease gelling agents.

Basic Principles. None of the inorganic gel greases proposed by their first inventors were marketable products. A short survey of the basic principles governing the behavior of such greases will clarify the nature and the solution of their innate shortcomings.

Suspensions of particles in liquids form gels only if forces act between the particles. This is most readily demonstrated by magnetizing a fluid oil suspension of powdered iron. Here the magnetic force causes the iron particles to interact one with another gelling the oil.

The bonding forces between particles must be large compared with the disrupting effects of the thermal molecular

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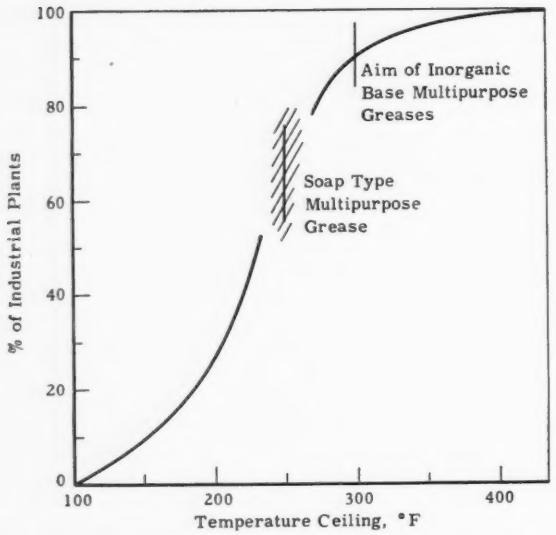

Fig. 1. Probable relationship between the temperature ceiling (for long term operation) of a multipurpose grease and the fraction of all industrial plants in the U. S. in which it might serve as a single grease (assuming it meets all other requirements).

motions in the system. In non-aqueous solvents when the particles are distant from each other, forces act which are generally attractive. These can be estimated to a fair approximation from the properties of the liquid and of the solid particles.[3] The magnitude of these forces is proportional to the difference between the cohesive forces of the solid particles and the oil, and are, therefore, generally the greater the more the two differ in chemical composition. These attractive forces pull the particles toward each other.

Once the particles are in contact, other forces come into play. If, as is often the case, the particle surface is covered with a skin of water, the cohesion of the particles is determined by the force necessary to break the liquid menisci and, therefore, depends largely upon the interfacial tension between water and oil. With "dry" particles, on the other hand, the pressure provided by the attraction forces mentioned above, or the nature of the chemical groups on the surface, may lead to the formation of interparticle bonds equaling the bulk strength of the particles (similar to those encountered in dry friction).

The magnitude and the range of the interparticle forces, as well as the requirements imposed by the lubricants' application, call for average particle diameters of less than about 1 micron. Commercial inorganic gel agents are of this size but have varied shapes such as spheres, short ribbons, platelets, needles, and porous sponges. All will gel petroleum oils at very low volume concentrations, some as low as 1.5%v. Differences in gelling ability have been found which may be due to the geometry of the particle. Often spheres are less effective gelling agents than anisometric particles, sponge-like gels being most effective when compared at equal attractive force.

In accord with one of the requirements for gelling, namely that a large difference exists in composition between oil and particles, the gelling particles are generally hydrophilic and, thus, easily displaced from the oil by water. Only organic particles, such as the soaps, the phthalocyanines, and similar organic pigments, some carbon blacks and also the new aryl urea derivatives, have a sufficiently large hydrophobic surface fraction to resist separation by water. The inorganic surfaces, therefore, have to be partially covered by hydrophobic substances to become water repellent. Complete coverage would so screen the force fields as to prevent the formation of a gel. The de-gelling, or deflocculating, effect of the hydrophobing agent is generally proportional to the extent of particle surface

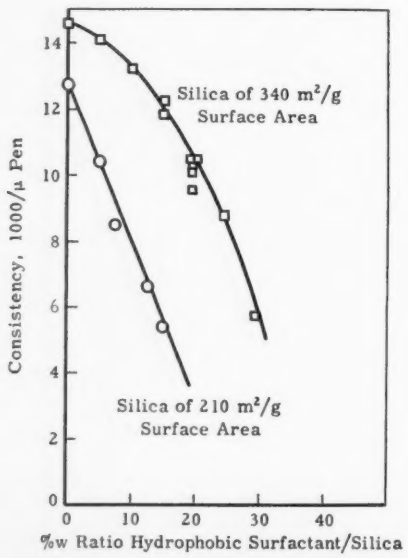

Fig. 2. Deflocing effects of surface coatings.

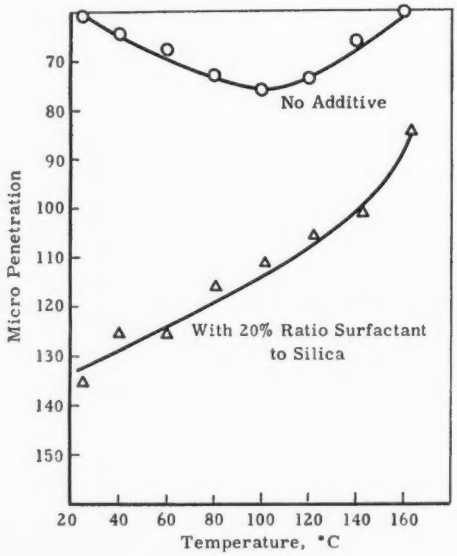

Fig. 3. Increased flocculation due to surface coating thermal desorption.

covered, as shown by the curves of Fig. 2. To maintain consistency with increased water resistance therefore, requires increased concentration of gel agent. Thus a compromise has to be reached between the required degree of water resistance and an economically desirable minimum content in gelling agent.

As a result of the desorption of the surface layer as the temperature is raised, the consistency of greases made from such coated particles may change with temperature, since the gelling effect is dependent on the extent of surface coverage. This is shown by the consistency vs temperature curves of Fig. 3. The strength of attachment of hydrophobing agents in typical inorganic base greases ranges from covalent and ionic bonding to simple physical adsorption on the particle surface; thus no general picture can be given of their consistency-temperature relations.

The extent of surface coverage by the water proofant also affects shear stability. Inorganic base greases, just like soap base greases, can be degraded by prolonged shearing such as occurs in the Shell Roll Test. But the mechanism of degradation is quite different. While most soap greases lose their consistency in this test because the fibrous soap particles are torn to isometric shreds, the inorganic base greases which have been studied soften because the small gel particles compact or snowball into relatively larger particles (see Fig. 4), and are thereby withdrawn from the gel network. As one should expect, this agglomeration process is very much retarded by the presence of the organic waterproofing layer on the gel particles. Inorganic base multipurpose greases, which must be water resistant, therefore exhibit generally excellent shear stability.

The consistency of inorganic base greases is extremely sensitive to the composition of the adsorbed layer on the particle surface. This is particularly apparent in their response to small amounts of moisture, as is illustrated by the steep consistency vs water content curves for silica gel grease on Fig. 5. The water undoubtedly adsorbs on uncovered islands of the particle surface, thus increasing greatly the interparticle cohesive forces. Whether this contribution derives from the interfacial tension forces mentioned above, or through some other mechanism, is not clear at present. All of the inorganic base greases which we have examined exhibit qualitatively similar consistency response to water and other flocculating agents, but the extent to which they do so differs rather widely among the various types of gelling agent-surfactant combinations. The irreversible consistency changes which some of the inorganic base greases exhibit after having been kept for some time at elevated temperatures, appear to be connected with a loss of moisture.

Several of the inorganic base greases, which exhibit a loss in consistency when stored at elevated temperatures, performed very well in high temperature field service. Therefore, some of the physical property correlations that predicted field performance for soap base greases may have to be revised when applied to these novel products.

Rust prevention in inorganic gelled greases usually requires the addition of suitable rust preventive agents. These agents also affect the consistency temperature curves since they may adsorb on the gel particles. Their adsorption, being in competition with the metal surfaces to be protected, critically determines the choice and performance of the rust preventive agent.

Performance Characteristics. The "simple" physical properties of greases described in the previous section are at least explicable in terms of an easily grasped physical picture of the various features of the microscopic gel structure. However, the grease performance tests, themselves simplified facsimiles of more complex field exposures, involve the interaction of so many variables that the results obtained

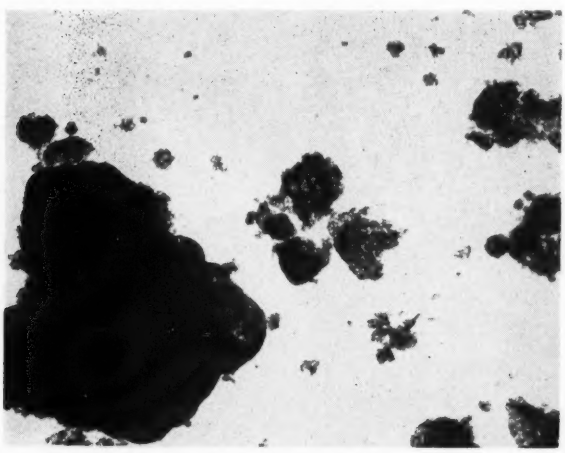

Fig. 4. "Snowballing" of unprotected silica particles in silica grease during Shell roll test.

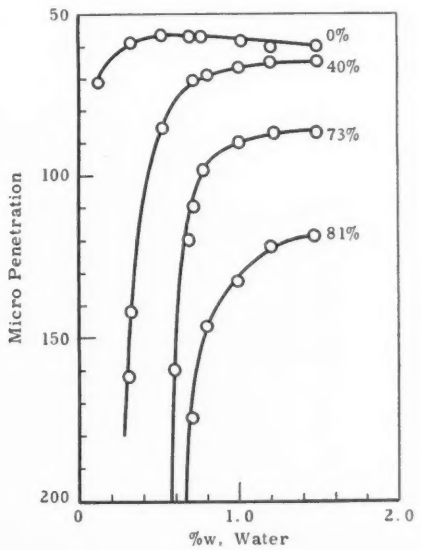

Fig. 5. Effect of water content on consistency; figures on curves refer to percent of surface covered by water proofant.

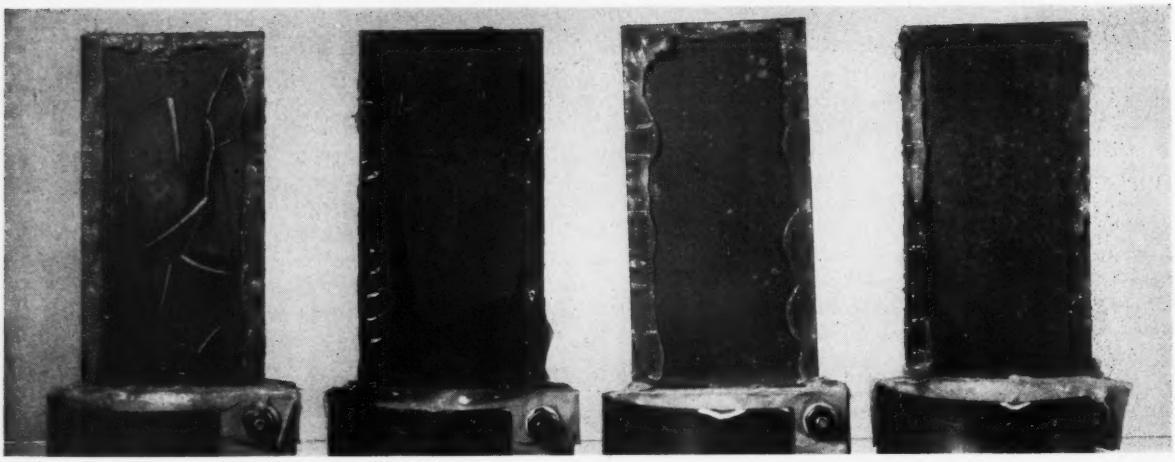

Fig. 6. Stripping of greases from metal surfaces by water; (left) experimental waterproof soap-base grease, (second from left) clay grease B, (second from right) silica grease C, (right) silica grease A.

with them should be described only as such. There are two performance features which particularly extend the usefulness of some of the inorganic gel greases; these are improved water wet and high temperature performance.

Water Wet Performance. This involves water resistance of the grease, lubrication in the presence of water, and corrosion caused by moisture.

No grease is truly water resistant. The above described surface characteristics of the gel particles, be they water insoluble soaps or partially hydrophobic inorganic solids, make them ideally suited as solid emulsifiers or at least as emulsion stabilizers. Hence the extent of water resistance is entirely defined in terms of the test which is applied to measure it. The test, in turn, must be related to the expected field service in order to be meaningful.

The data of Table I show that all of the commercial inorganic base greases meet the usual test requirements for water resistance. In some of the more severe tests, such as the water-roll test, several of the inorganic greases appear to excel the best multipurpose soap base greases in resistance.

Water resistance is of little practical meaning, however, if the grease is displaced from the bearing surfaces by water, since it would then be unable to lubricate a water wet bearing. We have observed bearings lubricated with some water resistant greases — soap as well as inorganic base — come to a grinding halt soon after injection of water in the course of one of our tests (i.e., the dynamic corrosion tests which will be described later on). The incipient stripping of the grease film is observed as a load increase on the wattmeter of the drive motor to the bearing. The stripping action of water on some greases is also demonstrated by the simple steel panel test shown in Fig. 6. Here the samples were submerged in water at 80 C. for 24 hours. Needless to say, a well balanced grease composition is not displaced from metal surfaces either by hot or cold water.

The first experimental, and even some commercial inorganic base greases, did not prevent corrosion. Extensive experimentation with field-correlated facsimile bearing tests, such as described in the Appendix, made us appreciate the need for careful balance in adsorption equilibrium for the rust preventive agent between the rather large gel

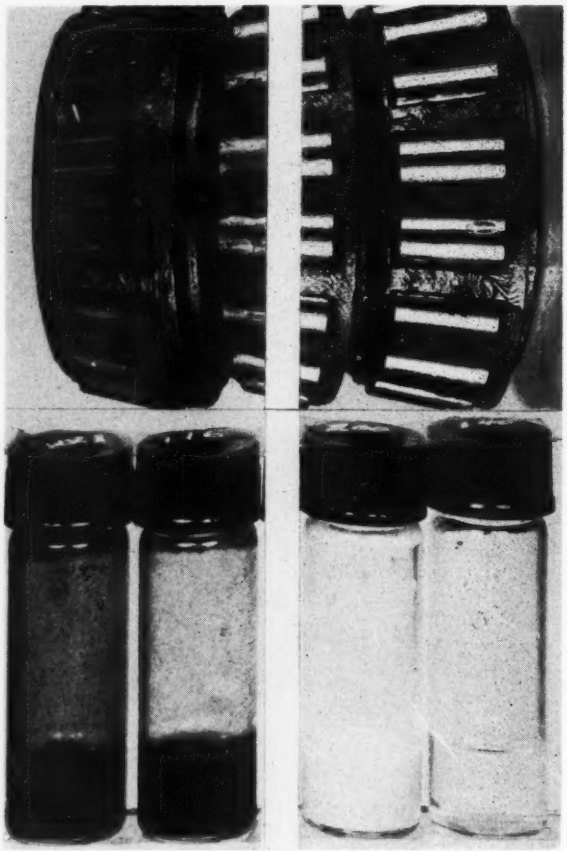

Fig. 7. Dynamic corrosion of water wet bearing completely eliminated by improvement in silica grease formulation; (left) Silica B, (right) Silica A.

particle surface (of the order of 5 to 25 m^2/gram of grease), the metal surface with which the grease is in contact (of the order of 0.01 m^2/gram of grease, if the lubricant layer is 0.1 mm thick), and the grease water interface.

The bearing test results on Fig. 7 illustrate the extent to which protection against dynamic corrosion in an operating bearing has now been achieved. The effect of the even more insidious static staining is shown in Fig. 8. Here the static etch marks, resulting from electrolytic attack in the contact areas of the rolling elements and races during rest periods of the water wet bearing, subsequently lead to complete bearing failures of the type shown in Figs. 8b and 8c. During operation the high local stress concentration around the etched areas may cause premature fatigue failure of bearings (Fig. 8b) or fracture of the cage by roller skidding (Fig. 8c). Greases can now be made which protect bearings against this type of attack for very long periods of rest or storage, as shown in Table II.

As a result of the new insight gained, it is now possible to make inorganic base greases which equal or exceed the rust protective ability of most multipurpose soap base greases at no sacrifice in high temperature properties as discussed in the following section.

Fig. 8. Static etching of water wet wheel bearings and resulting bearing damage.

Bearing Performance at Elevated Temperatures. One of the primary incentives for development of inorganic base greases has been the expectation of improved high temperature performance in comparison with equivalent soap base greases. Such performance is the result of a combination of properties deriving from both the gelling agent and the oil. Even the most stable gelling agent is of no avail if the lubricating fluid evaporates or oxidizes to a tar. In this respect, the new greases pose the same problems of proper choice of oils and antioxidants as the old. The ability of some inorganic base greases to set somewhat at elevated temperatures may assist them in staying in the bearing, where soap greases would soften and run out. In other cases the oxidation products of the oil might lead to undue softening of the grease due to adsorption and consequent deflocculating of the gel. Only bearing and field tests have so far been able to give

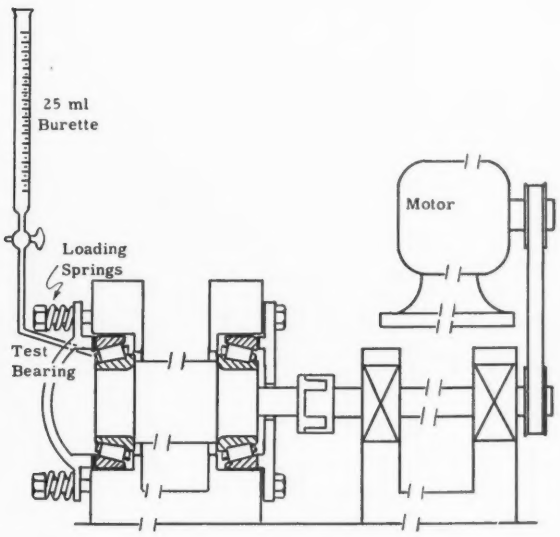

Fig. 9. Sketch of wheel bearing corrosion test rig.

Table I. Water resistance of typical inorganic base greases. Key: a) According to test procedure of U. S. Spec. ANG 3a; b) According to test procedure of U. S. Spec. ANG 15; c) Shell roll test on grease containing 20% admixed water; d) Experimental greases; e) Experimental greases made from purchased gelling agents; f) Purchased grease; g) Entered for comparison purposes: typical data for best compositions.

Grease	Water Absorption, % (a)	Bearing Washout, % (b)	Water Roll Life, hrs (c)	Lubrication of Water Wet Bearing
Silica A [d]	80	1.5	7	good
" B [e]	15	<1	>10	very poor
Clay A [d]	90	0.5	36+	good
" B [f]	90	1.0	16	fair to poor
" C [e]	135	-	>150	poor
L. Soap Multipurpose [g]	<100	<2	>4	good

the final answer to such questions. Tables III and IV present the rather favorable answers to these questions. Conditions can undoubtedly be chosen to come to rather different conclusions. The bearing operating conditions described on these tables were chosen to represent typical industrial applications.

Summary. The evidence to date indicates that the mechanical properties and the water resistance of inorganic base greases can be understood in terms of the fraction of gel agent surface covered by waterproofant and surfactant. A careful adjustment of this fraction is required to obtain good water resistance and rust preventive ability without significant loss of grease consistency.

This has been achieved, to varying degrees of success, through the use of very different techniques. In some cases the hydrophobic groups are attached to the surface by chemical bonds, i.e., covalent in the case of the esterified silica surface, and ionic in the case of the organo-bentonites. In other cases they are held by the forces of physical adsorption, i.e., amines and alcohols in non-swelling clay and soaps, and alcohols or amines on silica in some of the authors' own experimental products.

Satisfactory performance in the critical areas of modern industrial multipurpose greases, i.e., elevated temperature and water wet performance, can be obtained simultaneously with some of these new inorganic-base greases. In other "standard" qualification characteristics for premium multipurpose greases, no serious difference can be detected between the best of these greases and the best multipurpose soap base greases currently on the market.

Fig. 10. Cosmetic jar containing lubricated bearing partially submerged in 12 ml of water (0.05%w NaCl solution).

Table II. Corrosion preventive ability of various inorganic base greases. Key: a) Grease samples are identical with those of Table I; b) Glass jar corrosion test is described in Appendix; c) Dynamic and static corrosion test in roller bearing are described in the Appendix, ratings are: 0 = bad corrosion to 10 = no corrosion; d) Bearing seizes as soon as water is injected.

Grease [a]	Glass Jar Test [b] Rating after 500 hrs	Dynamic Corrosion Rating [c]	Static Corrosion Rating 24 hrs After Running [c]
Silica A	5	10	10
" B	0	fails [d]	fails [d]
Clay A	10	10	10
" B	0	4	0
" C	0	7	0

Table III. Performance of various inorganic base greases at elevated temperature. Key: a) Grease samples are identical with those of Table I; b) Single ball bearing, type 206K, operating at 1750 rpm, at 12% of design load (cycles are each 20 hrs at specified temperature); c) Quadruple ball bearing, type 206K, operating at 3600 rpm, at 12% of design load (cycles are each 20 hrs at specified temperature); d) Exhibits strong superficial set (increase in consistency); e) Data obtained in the ABEC test at the same temperature.

Grease	CRC Wheel-bearing Test 6 hrs, 110° C.	Navy Bearing Test 118° C. (250° F.) hrs to failure	Special Ball Bearing Tests at 150° C. Cycles to Failure a [b]	Special Ball Bearing Tests at 150° C. Cycles to Failure b [c]
Silica A	OK [d]	600 to 2000 [e]	-	>15
" B	OK	-	-	-
Clay A	OK	>700	>20	>20
" B	OK	-	17	-
" C	OK	-	-	-
Li Soap Industrial Multipurpose	OK	600	10-12	10-12

APPENDIX

Wet Wheel Bearing (Dynamic) Corrosion Test. Apparatus. Fig. 9 shows a sketch of the apparatus used in the wet bearing performance test discussed in this paper. Basically, the machine consists of two Timken tapered roller bearings mounted back-to-back on a rotating shaft. The bearings are loaded axially by four calibrated springs to the maximum rating specified by the manufacturer's catalog. A 25 ml burette suitably supported near the front (test) bearing holds the water used to contaminate the bearing while running. Bearing temperature is uncontrolled

Table IV. High temperature performance of special inorganic base grease in comparison with commercial high temperature greases. Key: a) Bearing type Fafnir 206K (25 mm bore) Conrad type ball bearing with ball controlled pressed steel separator.

Grease	10 hr Cycles in Bearing[a] at 200° C.
Purchased High Temperature Soap Grease A	6
Purchased High Temperature Soap Grease B	5
Purchased Clay Base Grease	< 2
Experimental Silica Grease	10-15
Cu Phthalocyanine in Silicone	>20

Table V. Operating schedule for bearing corrosion test.

Elapsed Time		
Hours	Minutes	
0	00	Start, load, record bearing temperature
0	05	Inject 2 ml H_2O, record bearing temperature
0	30	" " " " "
1	00	" " " " "
1	30	" " " " "
2	00	" " " " "
2	20	" " " " "
2	30	Record bearing temperature - stop.

and is measured by a thermocouple in contact with the outer race. The bearings are equipped with grease retainers having sufficiently large cavities to hold at least 10 ml of water within the bearing compartment.

Test Procedure. Approximately 20 grams of grease are required for one test. The bearing is packed by hand with 8 to 10 grams of the test grease, and the inside surfaces of the bearing compartment are coated with a thin film of the grease. After assembly, the machine is started at very light load and is rapidly brought to the desired test load while running. The first injection of water (2 ml) is made 5 minutes after starting, and subsequent 2 ml injections are made in accordance with the test schedule shown in Table V.

The pertinent data of the test and the operating conditions employed are shown in Table VI. At the end of the 2½ hour operating period and after inspection for dynamic corrosion, the bearing cone is assembled in its outer race and placed in a covered glass crystallizing dish (3 inches in diameter) in contact with all the water collected from the run. The water must be carefully poured over the bearing so that it penetrates through to the bearing rollers and has ample opportunity for metal contact. In this static corrosion phase of the test, the bearing is allowed to remain undisturbed for 24 hours and then inspected for rust stains on its working surfaces.

Glass Jar Corrosion Test. This is a test procedure for evaluating the moisture corrosion of non-operating, grease lubricated bearings. To simulate observed field conditions, a short period of operation of the test bearing is followed by a long non-operating period in which the bearing is in contact with water. The water is introduced after operation has ceased.

Test Apparatus and Procedure. A bearing (Timken cone No. 15118 and cup No. 15250-X) is packed by hand

Table VI. Specifications and operating conditions for dynamic corrosion test.

Bearing:	
Timken tapered roller	Cone No. 15118 Cup No. 15250-X
Driving motor:	Single phase, 60 cycles AC 110v, 1/4 hp, 1750 rpm
Water for contamination:	Distilled H_2O plus 0.05%w NaCl
Operating Conditions:	
Speed	1750 rpm
Load (axial)	530 lbs (catalog rating)
Temperature, °C.	Not controlled but usually 70-85
Total water injected	12 ml
Test duration, hrs	2-1/2 operating: 24 non-operating

with approximately 8-10 grams of the test grease, and after packing is placed on a drill press spindle and rotated for one minute at 1750 rpm with an axial load of about 40 pounds. The bearing and outer race are removed from the spindle undisturbed, and placed in a clear glass 8 oz. cosmetic jar (cone bore axis vertical and major diameter of the tapered rollers facing up). 12 ml of water, containing 0.05%w NaCl, are poured over the bearing cone, particularly over the spaces between the rollers. Fig. 10 shows a photograph of a test in progress.

Bearing Inspection. The bearings are inspected at desired intervals (24, 250, 500 and 1000 hours are suggested periods). Interruption of the test for inspection will not affect the results if care is used, but preferably separate tests are set up for each time interval. At each inspection the condition observed is rated from 0 to 10, in which 0 denotes very heavy corrosion and 10 no corrosion. The rating assigned should reflect both the working area covered by, and the depth of, the resulting corrosion.

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Electron Microscope Study Of Lubrication & Wear

by S. B. Twiss, C. R. Lewis & D. M. Teague*

The specimens used in this study were crossed steel cylinders, one cylinder rotating, the other being stationary. Under these conditions of high unit loading, wear particle size, damage of the metal contact surface, and wear rate increase with increasing original surface roughness of the moving metal part.

The type of lubricant strongly affects the wear process. Wear with purified mineral oil produces extremely minute particles, possibly by extensive and continuous microscopic welding of the sliding surfaces, due to rupture of the simple hydrocarbon film under the high unit loads. In contrast, ethyl palmitate or a 5% addition of sperm oil to mineral oil provides improved boundary lubrication, larger and fewer wear particles, little welding, and an extremely smooth surface except for occasional deep scratches.

The wear of metals, although a universally experienced phenomenon, is not completely understood. The number of factors involved in wear and the difficulty of controlling them experimentally makes this subject a difficult one to study successfully. Bowden and Tabor have discussed at length the effect of many variables on friction and wear.[1]

A recent survey of the extensive literature on the subject of friction and boundary lubrication has revealed a general agreement that the primary mechanism of sliding friction is the formation and rupture of minute "bridges" between the asperities of the sliding surfaces.[2] The same mechanism appears to be operative in causing metallic wear, where, in the process of rupturing such bridges, metal particles are torn loose from the surfaces. Many workers have demonstrated that metal transfer occurs even in the case of lubricated friction. It is probable that the transferred metal, remaining as asperities or raised areas on the metal surface, act to abrade particles from the mating surface.

The purpose of the present study was to obtain more detailed knowledge of these features of lubrication and wear by the use of the electron microscope. This appeared to be an ideal instrument to study at high magnification the metallic particles torn loose from the surface by rupturing of the minute welded areas and by abrasion of the surface. It was of interest, also, to determine the possibility of observing directly the presence of transferred metal on one of the surfaces, which should appear as raised areas at high magnification. Since surface finish, type of lubricant, and metal composition are known to significantly affect wear, these variables were included in this study.

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APPARATUS. The friction wear apparatus employed in this study has been described in detail by Burwell and Strang.[3] Sliding friction under high unit loading was produced. The wear occurred at the contact of two cylindrical specimens mounted with axes perpendicular to each other. One cylinder was rotated at a fixed speed while the other was pressed against it with a fixed load, producing an essentially circular wear area on the rider. A light micrograph of a typical wear scar is shown in Fig. 1, at a magnification of 60 X. The surrounding, original surface was ground (20 microinch roughness), while the worn contact area is much smoother—almost featureless under the light microscope.

Lubricant was applied to the surface in the form of a drop at the contact point of the two cylinders, remaining there throughout the test due to surface tension effects. The primary variable studied in this program was the effect of surface finish of the wearing surfaces, although a few tests were made with different specimen metals and lubricants.

Most of the work was done with specimens having standard automobile engine piston pin dimensions.

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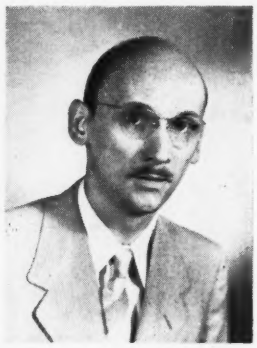

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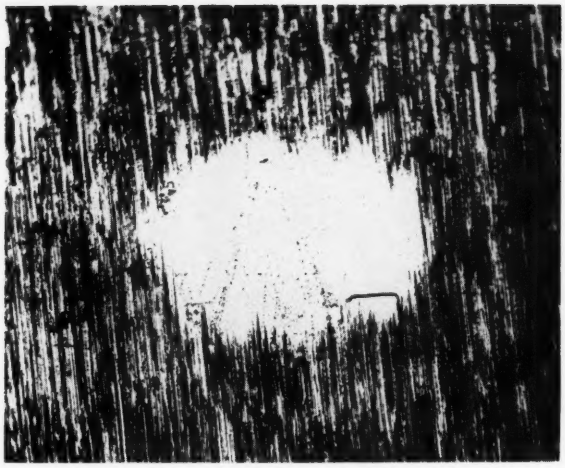

Fig. 1. Wear contact area. (Light optical micrograph, 60 X)

but consisting of S.A.E. 4027 steel, gas carburized for thirteen hours at 1680-1700 F., quenched in oil and tempered at 300 F., resulting in a surface hardness of 62.5-64.0 Rockwell C. The tests were run for two hours at a load of 2100 grams with a surface speed of 8.63 feet per minute, using a highly refined white mineral oil as the lubricant. A few exceptions to these test conditions will be noted as the individual tests are described.

ELECTRON MICROSCOPE TECHNIQUES. The wear surface was examined electron microscopically by means of replicas.[4] In brief, a dilute solution of formvar in dioxane or chloroform was flowed onto the specimen surface. After the solvent had evaporated, the plastic replica film was supported with a wire grid and stripped from the wear surface. The replica was then vacuum-shadowed with chromium or aluminum-gold at an angle of 45 degrees to the surface. Direct-printed electron micrographs of negative replicas prepared in this manner have the same relative appearance as though the original specimen surface, itself, were being observed.[5] Metal shadowing enhances resolution and aids in the interpretation of surface contours by providing a three-dimensional appearance.

Although the specimen surface was a curved cylinder, no serious difficulty was encountered; the replica supporting grid was curved beforehand to lie flat against the surface. The support grid was centered over the wear contact impression (which was frequently very small) with the aid of a binocular light microscope. Wherever possible, the replica was located so that part of the wear impression, as well as the surrounding unworn surface, could be observed in the electron microscope.

The metal particles produced by wear were deposited principally at the trailing edge of the stationary cylinder wear impression. The distribution and appearance of these particles were observed by carefully degreasing the specimen surface without disturbing the particles and flowing a dilute solution of formvar over the surface. When dry, the film of plastic containing the metal wear particles embedded in it was stripped from the surface and observed in the electron beam.

RESULTS. Fig. 2 is an electron micrograph at 10,000 diameters of the original 1.5-3 microinch ("Superfinished") surface of the cylinders used in some of the tests. The multidirectional scratches are characteristic of the surface finishing technique and distinguish it from the rubbing contact impression, where the scratches are all parallel to the direction of rubbing.

White Mineral Oil Lubricant. A series of experiments were made in which load, sliding speed, duration of test, and lubricant (mineral oil) were constant, while surface finishes of the two cylinders were varied. Table I gives the conditions of test, wear results, and lists the figure numbers of the electron micrographs for each test.

The wear in micrograms of the rider was determined from the volume lost during wear multiplied by the density. Volume of metal lost was calculated from the measured diameter of the wear impression

Fig. 2. Original 1.5 to 3 microinch ("Superfinished") surface of the cylinders used in some tests. (10,000 X)

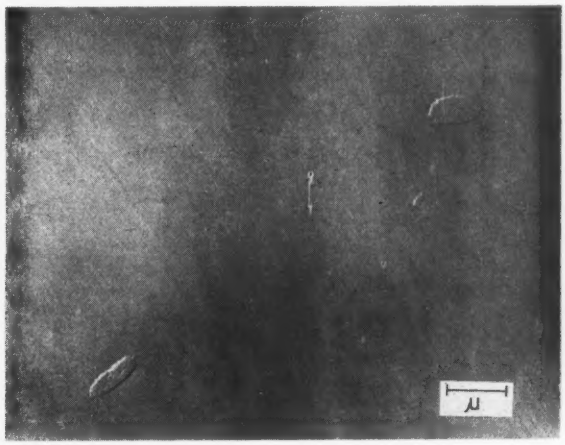

Fig 3. Wear surface. Rotor, 1 microinch; rider, 3 microinches. Mineral oil lubricant. (10,000 X)

and the known radius of the specimen.

It appears that the rotor finish has a greater influence on the wear rate than the rider finish. This may well be due to the fact that a larger area of the rotor is involved in the wearing process. The effect is even more marked with a soft rider and hardened rotor.[6]

For Test No. 1, the rotor was carefully finished to a smoothness of less than 1 microinch, while the rider had the 1.5-3 microinch surface finish. Fig. 3 is an electron micrograph at 10,000 X in the wear area on the stationary cylinder produced by the rubbing of the rotor. The worn surface is extremely smooth with minute parallel scratches, excepting for the very few raised areas illustrated which suggest localized welding and metal transfer from the rotor to the rider.

The wear particles deposited at the trailing edge of the wear area may be seen in Fig. 4. Although some larger particle agglomerates are visible, the wear particles are surprisingly small.

Fig. 5 shows the wear area surface in Test No. 2. Both metal parts had the 1.5-3 microinch surface finish. The worn surface contains small parallel scratches which are slightly larger than with the smoother rotor of the previous test. Slightly more evidence of welding is also visible in the raised areas of the wear scar.

The wear particles produced during this test may be seen in Fig. 6, magnified 25,000 times. The wear of this specimen was greater and the amount of particles produced was more voluminous than in Test No. 1. However, although there is considerable agglomeration, these particles are also extremely small, 5-10 millimicrons in size.

Micrographs are not included for Test No. 3, since the results were intermediate between those of Tests No. 2 and No. 4. The wear surface showed evidence of slightly greater areas of metal transfer and sizes of wear particles were slightly larger than in Test No. 2. The weight loss, shown in Table I, indicates the intermediate wear character of this test.

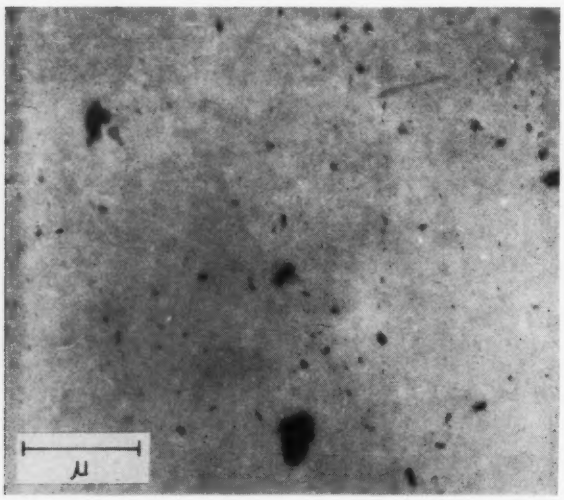

Fig. 4. Wear particles. Rotor, 1 microinch; rider, 3 microinches. Mineral oil lubricant. (20,000 X)

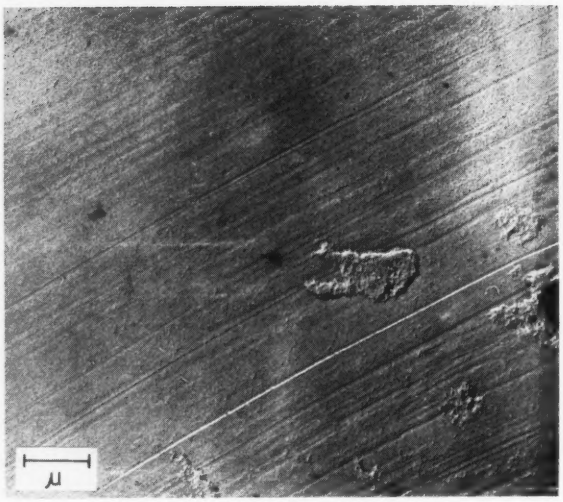

Fig. 5. Wear surface. Rider and rotor, 3 microinch finish. Mineral oil lubricant. (10,000 X)

The next test illustrated, No. 4, used a rotor with a 3 microinch superfinished surface running against a 20 microinch ground surface on the rider. Although much of the worn surface is relatively smooth and blank, according to an examination of representative micrographs from this test, some areas (Fig. 7) contain large scratches and more severe welding than in the previous tests. The surface within this wear impression is still much smoother than the original ground finish, which would appear tremendously rough at a magnification of 10,000 X, (Fig. 8).

The wear particles are also much larger, according to Fig. 9, than with the previous tests. A suggestion of the widely spaced irregularities characteristic of the original ground surface may be seen in the background of Fig. 9.

In Test No. 5 the surface finishes of the rotor and rider were reversed, with a 3 microinch surface on the rider and a 20 microinch ground rotor. Fig. 10 indicates severe galling or welding of the contact

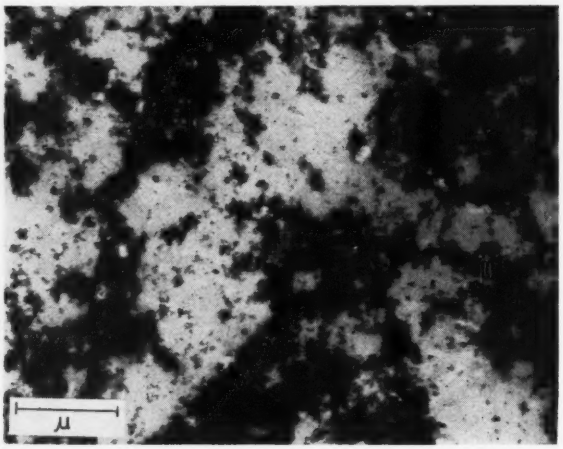

Fig. 6. Wear particles. Rider and rotor, 3 microinch finish. Mineral oil lubricant. (25,000 X)

Fig. 7. Wear surface. Rotor, 3 microinch; rider, 20 microinch finish. Mineral oil lubricant. (10,000 X)

surface over some portions of the contact area. Other areas on this specimen contained moderately deep parallel scratches, though the surface is considerably smoother than the original ground rotor. Fig. 11 shows a few typical wear particles from this test. These are several orders of magnitude larger than the particles resulting from wear of the smoother surfaces. Reference to Table I indicates that the greater surface damage and larger wear particles are also associated with greater weight loss.

In the above series of tests, mineral oil was the lubricant and all conditions, other than surface roughness, were constant. The significant conclusions from these electron micrographs and wear results are that wear particle size, wear surface smoothness, and wear rate all decrease as the initial surface finish of the test specimens is made smoother. Moreover, electron micrographs indicate that surface changes suggesting seizing and galling also decrease as the initial surface becomes smoother. The smoothness of the wear area in the stationary member is most closely related to the finish of the rotor, and tends to be smoother than the original surfaces. Although it has long been suspected that wear particle sizes decrease with decreasing wear rates, this work is believed to be the first explicit experimental proof of this hypothesis. It is understandable that if the wear particles are produced by rupturing welded areas, the smoother the surfaces the smaller the welded areas and the resulting wear particles. Similarly, wear particles produced by abrasion will be smaller as the raised areas due to metal transfer are reduced in size and number by the smoother surfaces.

A recent paper by Rabinowicz[7] has given wear particle sizes an order of magnitude greater than those shown here. We believe that the method used by Rabinowicz was incapable of resolving the extremely small particles since they are almost at the lower limit of resolution of the electron microscope.

Comparison of Different Lubricants. Another series of experiments was made to study the effect of type of lubricant on wear. Surface finish of the specimens (3 microinches) and test conditions, other than lubricant, were kept the same as those described previously.

Lubrication of the cylinders with white mineral oil resulted in the friction wear surface shown in Fig. 5. As noted in this and several other duplicate tests, small scratches are present, along with slightly rough areas of the surface, which might be interpreted as metal-to-metal welding and metal transfer on a very minute scale. With ethyl palmitate as the lubricant, on the other hand, a number of large scratches are seen in the wear area, but the surface between the scratches is smooth, even at a magnification of 10,000 X, as shown in Fig. 12.

A similar contrast was noted with the wear particles. When white mineral oil was the lubricant, the metal particles produced by frictional wear were extremely small, 5-20 millimicrons, barely resolvable at a magnification of 25,000 X (see Fig. 6).

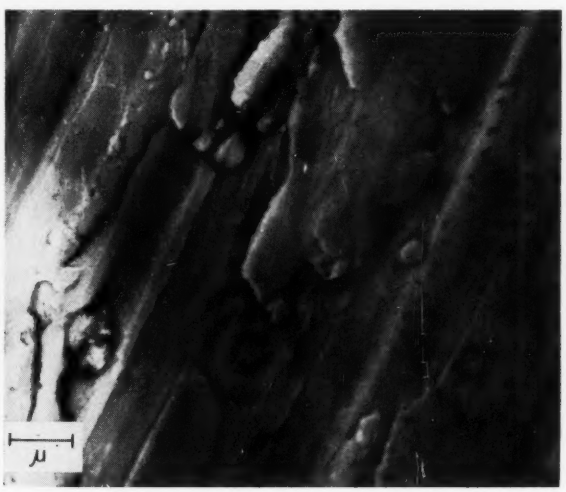

Fig. 8. Original ground surface, 20 microinch roughness. (10,000 X)

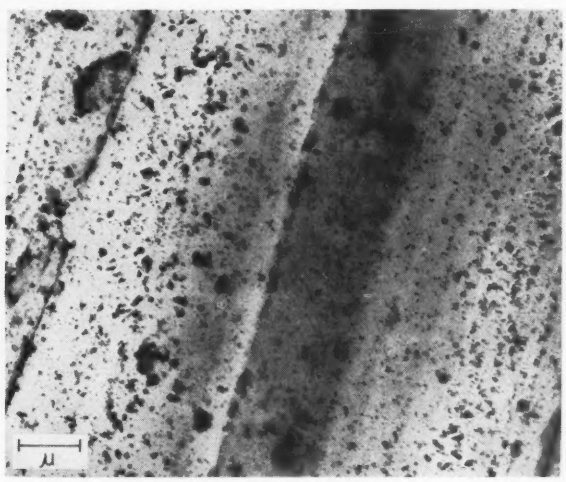

Fig. 9. Wear particles. Rotor, 3 microinch; rider, 20 microinch finish. Mineral oil lubricant. (10,000 X)

This result was duplicated numerous times. However, lubrication of the cylinders with ethyl palmitate yielded metal wear particles several orders of magnitude larger. Examination of these particles at very much lower magnification, Fig. 13 at 2000 X, indicates that most of them are large and elongated, with a major dimension of about one micron.

With all specimens having the same 3 microinch finish, the wear with the ethyl palmitate lubricant was approximately one-half that observed with mineral oil lubricant.

Results somewhat similar to those obtained with ethyl palmitate resulted from lubrication with mineral oil containing 5% sperm oil. Observations with the electron microscope revealed wear particles with an average diameter or 75 millimicrons, appreciably larger than those produced with straight mineral oil.

These results indicate surprisingly different wear characteristics, depending on the lubricant. Additional studies should be made to establish the basic causes of these differences. It has been generally stated that straight mineral oil functions as a lubricant only as long as a hydrodynamic film of hydrocarbon is maintained between moving metal surfaces, although evidence has been presented indicating that mineral oils may form solid films in high pressure bearings.[6] Under the very high unit loads characteristic of this test, almost continuous rupture of the film apparently occurs, with metal-to-metal contact and galling. This may account for the general microscopic roughness of the wear area. Welding occurs continuously on a minute scale and produces minute wear particles.

Ethyl palmitate on the other hand, according to other studies on this subject,[2, 8] is a boundary lubricant. Esters are capable of hydrolyzing slightly, and the fatty acid formed can react with active metals to form a soap which functions as a boundary lubricant at temperatures up to its melting point. The few large scratches and wear particles observed with this lubricant may be the result of occasional film

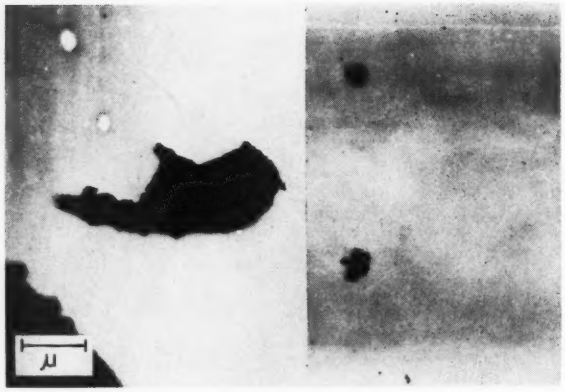

Fig. 11. Wear particles. Rotor, 20 microinch; rider, 3 microinch finish. Mineral oil lubricant. (10,000 X)

failure, where localized heating has exceeded the melting point of the soap.

Little evidence is visible of metal seizing or welding with ethyl palmitate lubricant, although with the electron microscope replica technique very large, rough welds might be missed.

The appearance of the worn surfaces suggest that during lubrication with mineral oil under boundary conditions, metal transfer from the moving member to the stationary member occurs (note that weld areas stand out in relief above the surfaces shown). Where metal transfer is extensive, and is increased by a greater roughness of the moving member, the wear increases. The mechanism of wear under these conditions, therefore, may include extensive, minute abrasion of the mating metal surface by the welded areas. This is apparently not the case with boundary lubricants; there are few galled areas indicative of metal transfer. Apparently, wear is caused by infrequent breakthrough of the boundary film, with little abrasive wear due to raised areas of transferred metal occurring. There is definite evidence of deep scratches due to plowing

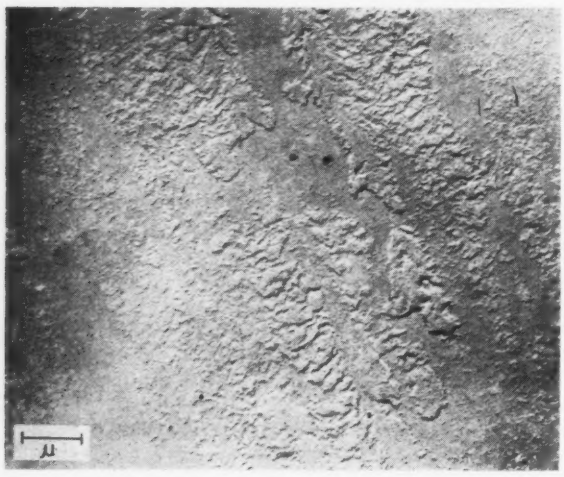

Fig. 10. Wear surface. Rotor, 20 microinch; rider, 3 microinch finish. Mineral oil lubricant. (10,000 X)

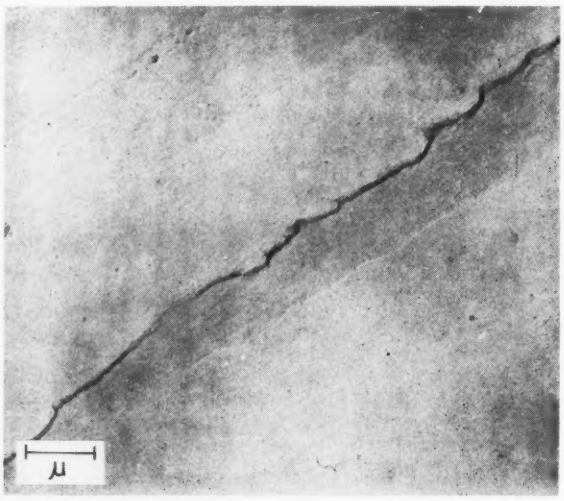

Fig. 12. Wear surface. Rider and rotor, 3 microinch finish. Ethyl palmitate lubricant. (10,000 X)

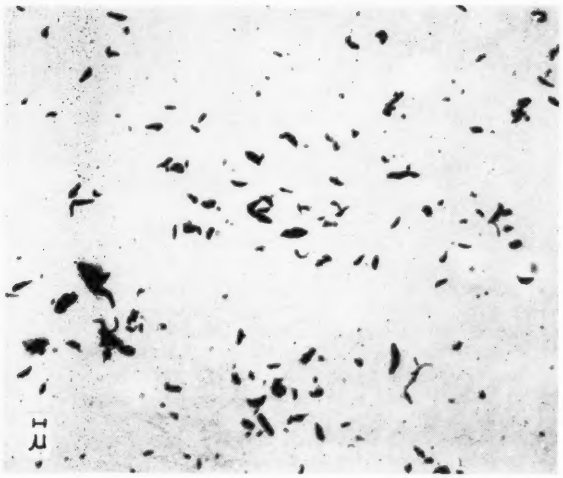

Fig. 13. Wear particles. Rider and rotor, 3 microinch finish. Ethyl palmitate lubricant. (2,000 X)

of the wear area by the larger particles formed in this case.

No Lubricant. To study the effect of metal-to-metal wear, two tests were run with no lubricant. In these tests the speed was maintained at 8.63 feet per minute, but the load was reduced to 1200 grams and the duration of running to ten minutes. The initial surface finishes and weight losses are indicated in Table III.

The appearance of the friction contact area from the first test is shown in Fig. 14, while the large wear particles produced may be observed in Fig. 15.

The surfaces from the second test were so rough that it was impossible to strip off replicas for electron microscopy. The metal removed from the rider on both tests was over forty micrograms in spite of the short duration of test, and both wear particle sizes and resulting surface roughnesses were high.

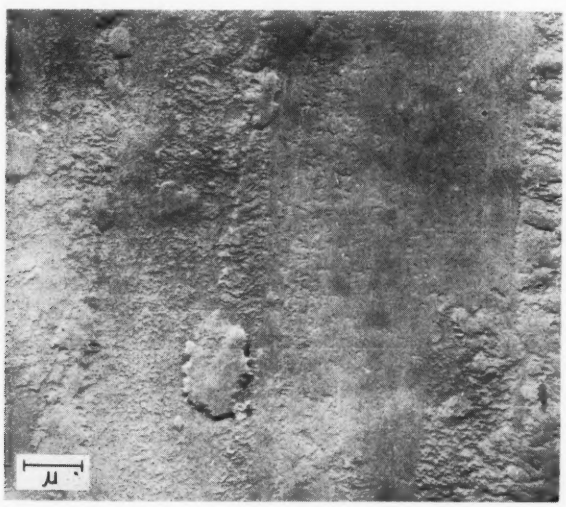

Fig. 14. Wear surface. Rotor, 1 microinch; rider, 3 microinch finish. No lubricant. (10,000 X)

Cast Iron Specimens. An additional test was made under mineral oil lubricated conditions using cast iron with a 3 microinch finish rather than carburized steel for the specimen cylinders. In electron micrographs of the wear area on the cast iron, some suggestion of welding is visible, and lamellar areas where graphite flakes intersect the metal surface can be seen. It may be readily understood how fragments of graphite, removed as the metal surface is worn, might improve lubrication of the contact area. The wear debris contained thin plates of graphite, and metal particles with a range of sizes.

SUMMARY. Studies of wear specimens with the electron microscope show that:

(1) With mineral oil lubricant, wear particle size, wear rate, and damage of the metal contact surfaces all decrease as the initial surface of the specimens is made smoother.

(2) The surface produced by frictional wear is generally smoother than the original surface (excepting where the rotor was initially much rougher). This characteristic is undoubtedly important in the break-in of moving parts, since during this process wear is known to progressively decrease.

(3) Wear with purified mineral oil produces extremely minute wear particles, possibly by extensive and continuous microscopic welding of the sliding surfaces, due to rupture of the hydrodynamic film under the high unit loads.

(4) In contrast, ethyl palmitate or a 5% addition of sperm oil to mineral oil provides boundary lubrication, larger and fewer wear particles, little welding, and a smooth surface, except for numerous deep scratches.

(5) The wear of unlubricated parts is characterized by severe scoring and welding, and produces large metal wear particles.

(6) The observed effects are quite compatible with the present theories of lubrication and wear involving the formation and rupture of minute welded areas by breakthrough of the lubricant film. Elec-

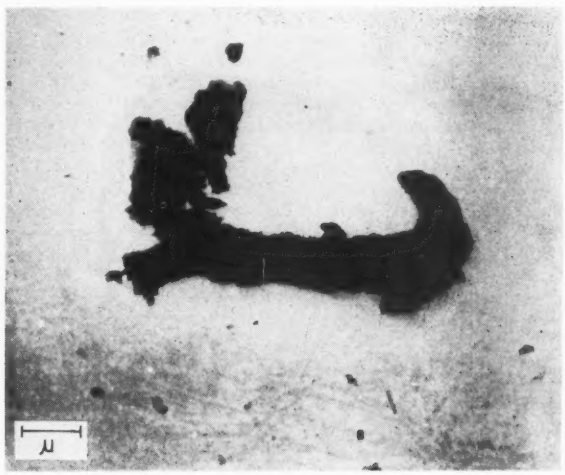

Fig. 15. Wear particles. Rotor, 1 microinch; rider, 3 microinch finish. No lubricant. (10,000 X)

Table I. Steel specimens lubricated with mineral oil. Conditions; load: 2100 grams; surface speed: 8.63 ft./min.; lubricant: white mineral oil.

Test No.	Rotor Finish, μin.	Rider Finish, μin.	Wear, Micrograms	Wear Surface, Fig. No.	Wear Particles, Fig No.	Particle Size mμ
1	1	3	Undetectable	3	4	10
2	3	3	0.8	5	6	9
3	1	20	2.3	-	-	-
4	3	20	6.6	7	9	65
5	20	3	11.5	10	11	440

Table II. Steel specimens with different lubricants. Load: 2100 grams; surface speed: 8.63 ft./min.; specimen surface finish: 3 microinch.

Test No.	Lubricant	Wear Surface Fig. No.	Wear Particles, Fig. No.	Particle Size, mμ
2	Mineral oil	5	6	9
6	Ethyl palmitate	12	13	600
7	Mineral oil, 5% sperm oil	-	-	75

Table III. Wear—Unlubricated Specimens.

Rotor Finish, Microinches	Rider Finish, Microinches	Wear, Micrograms	Particle Size, mμ
1	3	41.2	20-3000
20	3	44.0	-

tron micrographs present direct evidence of metal transfer during wear, and suggest that the minute wear particles formed in the case of mineral oil lubrication may be due in large part to abrasive wear.

(7) The ability of the electron microscope to observe directly very minute changes in surface, wear particle size, and shape, makes this a useful tool for investigating wear under conditions such as boundary lubrication where the effects are not easily observable by other techniques.

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COMMENTARY by A. Dobry (Westinghouse Research Laboratories). This paper does a great deal to clear up some hitherto obscure points in wear phenomena. The authors' results seem to fit a very simple picture of the wear process remarkably well.

If the geometrical shape of the surface remains fixed, any change in the valley to peak height (surface finish) will be directly proportional to the change in the diameter of the asperities. The size of the wear particles torn from the asperities should be proportional to the size of the asperities. Therefore, the diameter of wear particles should be directly proportional to the surface finish. The results presented here seem to fit this picture.

Furthermore, since the actual contact area will be constant for a fixed load, the total number of contacts times the square of the average contact diameter will be constant. The total amount of material removed will be proportional to the number of contacts times the cube of the average contact diameter. Therefore, other things being equal, the amount of wear will be directly proportional to the wear particle size and, consequently, directly proportional to the surface finish. If one plots the authors' values for wear against the wear particle size using mineral oil lubrication, one gets a fairly straight line.

Of course, as wear proceeds, the surface roughness decreases. These results would seem to imply that the average surface finish during the wear process is directly proportional to the original surface finish.

The results with mineral oil seem to be quite different from those with other lubricants, although they may also correspond with the results in the case of unlubricated wear. It would be interesting to see if these relations between surface finish, wear, and wear particle size also hold for other types of lubricants with different constants of proportionality for different lubricants.

COMMENTARY by M. C. Shaw (Massachusetts Institute of Technology). The authors have clearly demonstrated in this paper the ability of the electron microscope to reveal the fine detail of surface damage that arises when metals are slid together under heavy load. It was found that the roughness of the wear scar increased as the lubricant became less effective, or as the initial finish became poorer. The amount of wear was also found to decrease as the lubricant became more effective. These results are to be expected from the generally accepted view of wear involving the formation and rupture of surface junctions.

An unexpected result was the observation that the wear particle size was greater with a good boundary lubricant than with pure mineral oil. The authors suggest that this might be explained if the wear with mineral oil were largely abrasive in nature, while that with the good boundary lubricant (ethyl palmitate) were due to a plucking action. It would appear however that just the reverse should be expected. That is, we should expect more plucking wear in the case of mineral oil due to the greater degree of clean metallic contact, but more abrasive wear with the boundary lubricant due to the large wear particles observed.

There is an alternative interpretation of the authors' results that appears to be in agreement with all observations. When steel is lapped with very fine loose abrasive particles (Al_2O_3), the abrasive particle size is found to grow if the conditions of temperature and pressure are too severe. Particles from 10 to 100 times the size of those introduced initially are found, and these result in large unwanted scratches. When the large particles are carefully examined

they are found to be sintered masses, black iron oxide constituting the continuous phase. The large particles are magnetic, since black iron oxide is magnetic.

It would appear that in the present case the wear particles as produced with the boundary lubricant are actually much smaller than those produced using mineral oil. Hence, the much smoother wear surface obtained with the boundary lubricant. The smaller wear particles should be expected to reach much higher temperatures upon being generated and upon being oxidized. These higher temperatures should result in a thicker oxidized layer that could serve as a sintering medium to produce large particles, as in the case of the aluminum oxide abrasive. The large scratches observed in the wear scar with the boundary lubricant would, of course, result from the abrasive action of the large wear particles as the authors suggest.

The question that naturally arises in connection with the above picture is why the boundary lubricant that is so effective in preventing wear is not equally effective in preventing wear particles from getting close enough together to sinter. The answer to this might lie in the fact that a material such as iron palmitate (the real boundary lubricant formed in situ on the surface) is only effective as a boundary lubricant to its melting point. When used as a boundary lubricant it becomes chemadsorbed on the iron surfaces at relatively low temperature. It will be effective as long as the mean surface temperature is below its melting point. When two high points tend to come together considerable heat is developed; but since time is required for melting, contact may be prevented by the metal salt even though nonequilibrium temperature far above the melting point may obtain instantaneously. However, should a particle be dislodged, it will be at very high temperature for appreciable time compared with the relaxation time associated with melting, and thus the molten or decomposed boundary film will be quite helpless to prevent welding. In fact, the oxidation product resulting from the action of such high temperatures upon the boundary lubricant might actually function to promote welding or sintering. According to this view, the basic difference between the boundary lubricant and mineral oil would lie in the initial size of the particles generated. Those produced in mineral oil would be of such a size and temperature that they would not sinter, while those produced with the boundary lubricant would be smaller, reach higher temperatures, and hence sinter.

The final word on whether large or small wear particles are produced with a good boundary lubricant, must await further investigation in which a greater surface area is scanned for evidence of large wear pits. The authors did not find any such pits, but suggest that this may have been due to the small field of view obtained at the high powers at which they worked. If large pits were to be found, this poses another very interesting question, namely, why a good boundary lubricant should cause the metal to be plucked out in larger pieces. About the only way this could be explained, if it were to be found, is in terms of what Rehbinder calls "hardness reduction." This idea, that has been widely studied in Russia but not substantiated in the Western World, holds that materials are weakened in the presence of adsorbable substances which are thought to promote crack growth. If such an action would occur, it could conceivably cause the cracks associated with wear particle formation to run greater distances and, hence, form larger particles in the presence of a boundary lubricant. However, this is not thought to be the case, and it would appear more probable that the large particles result from a sintering action rather than being born that way.

AUTHORS' CLOSURE. The quantitative interpretation of the data by Dr. Dobry appears to be sound, and forms an attractive working hypothesis for further studies. The authors, however, prefer to hold in abeyance any quantitative conclusions until more evidence is available covering a wider range of metals and lubricants. This work shows that the systematic application of the electron microscope to wear studies is capable of providing a basis for greatly enhanced understanding of the wear process.

The theory presented by Dr. Shaw to explain the apparent formation of larger wear particles with ethyl palmitate is very interesting. Its validity, however, can be proved only with considerably more results than are presented here. The authors suggest that the small sized but voluminous wear particles produced during mineral oil lubrication are due to both metal removal by seizing and abrasive wear. Abrasive wear includes the action of loose particles as well as plowing by the rough galled surface as shown in Figs. 3, 5, 7 and 10. These raised areas are undoubtedly produced by plucking or metal transfer from the rotor to the rider surface. Unfortunately, the rotor surfaces were not examined in the electron microscope, so no direct evidence is available concerning the presence of wear pits on the mating surfaces. The absence (or reduced amount) of such raised areas, in the case of ethyl palmitate lubricant, indicates that much less metal transfer or welding occurred. This is understandable because a boundary lubricant film has antiwelding properties. The wear, in the case of the boundary lubricant, was assumed, therefore, to be due primarily to plowing by a few large particles, with little wear due to raised areas. This theory explains the greater amount of wear particles and the higher wear rate in the case of mineral oil lubrication; it does not explain why large particles should form with a boundary lubricant and only small particles with mineral oil.

Dr. Shaw's suggestion that the wear particles can grow or sinter during the process of wear has certain deficiencies. In the first place, the only source of energy is that due to friction and, since the friction with both lubricants is approximately the same, it would be expected that sintering would occur to an even greater extent with the mineral oil lubricant. In addition, the presence of the chemically formed palmitate film should interfere with sintering to a greater extent than the oil film. Desorption or removal of the lubricant film by heat and pressure must occur before metal-to-metal contact is established between particles.

The hypothesis that the authors wish to advance takes into account the greater polishing action of the ethyl palmitate lubricant, which produces smoother surfaces than the mineral oil lubricant. Very smooth surfaces for the former lubricant were observed in the electron micrographs. Since the same loads were involved in experiments with both lubricants, the load supporting area must also be the same. These areas, in the case of the smooth, polished surfaces produced by palmitate, should be fewer in number but larger in area than with the rougher mineral oil lubricated surfaces. Therefore, whenever the palmitate film is broken through and welding occurs, the welded areas should be much larger. The resulting wear particles should be several times larger than the particles resulting from the more numerous but smaller welded areas obtained with mineral oil. Further work in this field is definitely needed to cast more light on this and other questions raised by the present study.

Plan to Attend!

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Power Loss In Elliptical & 3-Lobe Bearings

by O. Pinkus*

The power losses for elliptical and three-lobe bearings, both symmetrical and asymmetrical, were derived as functions of the customary bearing parameters and bearing ellipticity. Expressions are given for two cases; one assuming a complete oil film, and one taking into account the incompleteness of the oil film in the diverging sections of the bearing. All equations are for a concentric shaft position, this being a plausible assumption as noncylindrical bearings are mostly used in low load, high-speed applications. For convenience the power losses for the noncylindrical bearings are plotted in comparison with those for cylindrical bearings of clearance c as given by Petroff's equation. Excellent agreement was found between the theoretical power losses and experimental results in bearings.

Nomenclature

D = diameter of bearing, in
H = power loss, horsepower
H_o = power loss in cylindrical bearings, hp
L = length of bearing, in
N = speed, rpm
R = radius of inscribed circle, in
U = linear velocity in/min
F_o = power loss in cylindrical bearings, in-lbs/min
F = power loss, in-lb/min
Z = oil viscosity, lb-min/in^2
L_f = width of oil film, in
R_l = radius of lobe, in
c = $(R_l - r)$, in
e = shaft eccentricity, in
h = oil film thickness, in
j = power loss factor due to ellipticity and incomplete oil film, dimensionless
j_o = power loss factor from the incomplete oil film portion of one lobe, dimensionless
k = power loss factor due to ellipticity, dimensionless
m = c_o/c, ellipticity ratio
r = radius of shaft, in
e_o = ellipticity of bearings, $(R_l - R)$, in
μ = oil viscosity, centipoises
θ_2 = angle at point of minimum film thickness, radians

Present day technology is, among other things, characterized by the advent of high-speed machinery. Hydrodynamic bearings called upon to operate under these conditions are confronted with some new problems, among which instability, known as oil whip, is one of the most prevalent and the most troublesome. Also power losses and, subsequently, bearing temperatures become excessive at high speeds, and new designs are required to cope with these difficulties. The existing high-speed bearings are characterized by their non-circular bores,[4] among which the elliptical and the 3-lobe bearings are the most popular.

In practice, the elliptical bearing is made up of two cylindrical halves brought together so that their centers are displaced several mils from the bearing center. This kind of bearing is manufactured conveniently by placing shims at the horizontal split and machining a circular bore. The shims are later removed, and the two halves brought together to produce the elliptical bearing, as shown in Fig. 1. The 3-lobe bearing comes in two variations: symmetrical and asymmetrical. The symmetrical 3-lobe bearing is made up of three 120° arcs, their centers displaced several mils from the bearing center. The asymmetrical 3-lobe bearing is commonly made up of a 180° portion on the bottom and two 90° sections on top. The geometry of both of these bearings is shown in Fig. 2.

In all these designs, convergent clearance regions exist even at a concentric shaft position, and their convergence increases with an increase in shaft eccentricity. This convergence creates high pressure regions which, in effect, put an additional load on the bearing—a factor known to enhance shaft stability. The extra clearance space, as compared with a circular bearing having a diameter equal to the inscribed circle, increases the oil flow, and also often reduces the power losses, resulting in lower temperature rises. For these reasons the elliptical and 3-lobe bearings are widely used in industry.

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Unfortunately, studies of the various non-circular bearings have not kept pace with their popularity. This

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paper deals with power losses in these types of bearings. It provides expressions for power losses as a function of the customary bearing parameters, as well as a newly defined variable, ellipticity. The analysis is carried out both assuming a full oil film as well as with an allowance for the incomplete oil film which surely exists in the diverging portions of the bearing. The method of including the effect of an incomplete oil film is that previously used by Rosenblatt and Wilcock[2] in their analysis of cylindrical bearings. The expressions are derived for a concentric shaft position, and thus they may be considered as equivalent to those given by Petroff for cylindrical bearings.[1]

ANALYSIS. Petroff's equation as obtained from the basic relationship

$$F = (\text{Shear Stress} \times \text{Area}) \times (\text{Linear Velocity})$$
$$= \left(Z \frac{U}{h} \times L \times 2\pi R\right) \times U = \frac{2\pi Z U^2 R L}{h} \quad (1)$$

can be written in differential form

$$dF = \frac{Z U^2 R L d\theta}{h} \quad (2)$$

For a cylindrical bearing, h is constant, and Eq. 1 gives the power loss. For non-cylindrical bearings the clearance is not constant, and an appropriate expression for h as a function of θ must be used. Following is the derivation of power loss expressions for three types of non-cylindrical bearings: elliptical, 3-lobe symmetrical, and 3-lobe asymmetrical. Like Petroff's equation, they are all based on a concentric shaft position.

FULL OIL FILM. The derivation of the expressions for power loss in this section assumes the existence of a complete oil film all around the bearing. This should yield power losses higher than those encountered in actual cases.

Elliptical Bearings. In Fig. 1 the diameter of the inscribed circle of the elliptical bearing is $2R$, while the radius of curvature of both arcs is $R + e_o$, e_o being here called the ellipticity of the bearing. When a shaft runs eccentrically in a cylindrical bearing, the thickness of the oil film at any point is given by

$$h = c + e \cos \theta \quad (3)$$

From an observation of Fig. 3 it is apparent that a shaft running concentrically in an elliptical bearing creates a situation similar to Fig. 3 with e_o, the ellipticity, taking the place of e, the eccentricity. This applies to both halves of the bearing. Thus, the oil film thickness in each half of an elliptical bearing can be expressed as

$$h = c + e_o \cos \theta \quad (4)$$

with θ going from $\pi/2$ to $3\pi/2$.

For a cylindrical bearing Eq. 1 gives the power loss. For an elliptical bearing where $h = c + e_o \cos \theta$, we have

$$dF = \frac{Z U^2 R L d\theta}{c + e_o \cos \theta} \quad (5)$$

$$F = 4 \int_{\pi/2}^{\pi} \frac{Z U^2 R L d\theta}{c + e_o \cos \theta} \quad (6)$$

where the integral is evaluated for one quarter of the bearing. This integrates (3) to

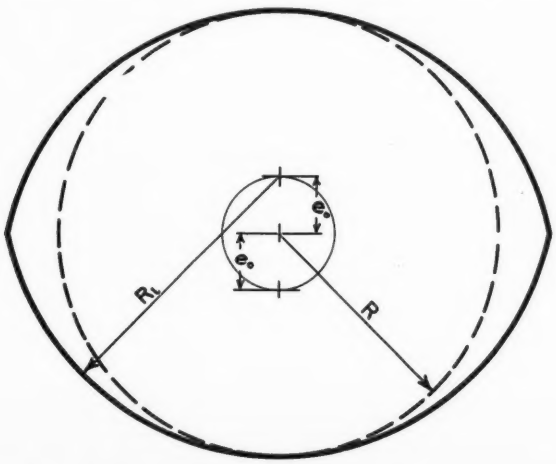
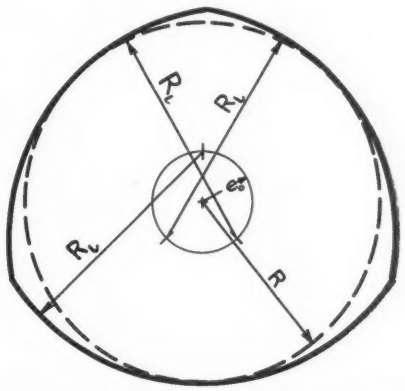
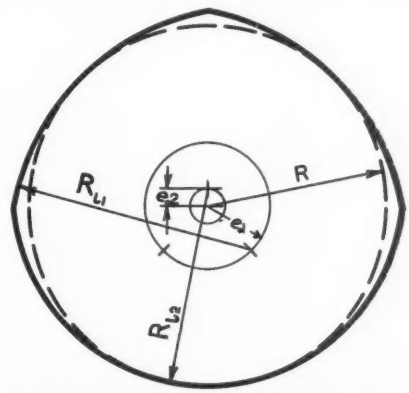


Fig. 1. Elliptical bearing.



a) SYMMETRICAL 3-LOBE BEARING



b) ASYMMETRICAL 3-LOBE BEARING

Fig. 2. Three-lobe bearing.

$$F = \frac{4ZU^2RL}{\sqrt{c^2 - e_o^2}} \arctan \frac{\sin\theta\sqrt{c^2 - e_o^2}}{c\cos\theta + e_o}\Bigg|_{\pi/2}^{\pi} \quad (7)$$

Evaluating the limits, we obtain

$$F = \frac{4ZU^2RL}{\sqrt{c^2 - e_o^2}}\left[\pi - \arctan\frac{\sqrt{c^2 - e_o^2}}{e_o}\right] \quad (8)$$

Rearranging the values

$$F = \frac{4ZU^2RL}{c\sqrt{1 - m^2}}\left(\pi - \arctan\frac{\sqrt{1 - m^2}}{m}\right) \quad (9)$$

When $e_o = 0$, which means that the bearing is cylindrical, the value of arctan ∞ is $\pi/2$, and Eq. 9 reduces to (1), Petroff's equation for a cylindrical bearing. When $e_o = c$ the shaft is rubbing against the bearing surface, and Eq. 9 gives an infmite power loss.

In practical terms of horsepower, Eq. 9 can be written as

$$H = \frac{1.2\,\mu N^2D^3L \times 10^{-13}}{c\sqrt{1 - m^2}}\left(\pi - \arctan\frac{\sqrt{1 - m^2}}{m}\right) \quad (10)$$

Symmetrical 3-Lobe Bearings. From an observation of Fig. 2, it is apparent that as far as each individual lobe is concerned, a shaft running concentrically in a 3-lobe bearing creates a situation similar to a shaft running eccentrically in a cylindrical bearing. In the 3-lobe bearing e_o, the ellipticity, takes the place of e, the eccentricity. The oil film thickness for each lobe can be expressed as

$$h = c + e_o\cos\theta$$

with θ going from $2\pi/3$ to $4\pi/3$ as shown in Fig. 4. We have then

$$F = 3\int_{2\pi/3}^{\pi} \frac{2ZU^2RL}{c + e_o\cos\theta}\,d\theta \quad (11)$$

where the integration is performed over one half of one lobe which is the symmetrical element of the bearing.

The integral of Eq. 11 evaluated between the limits of π and $2\pi/3$ yields

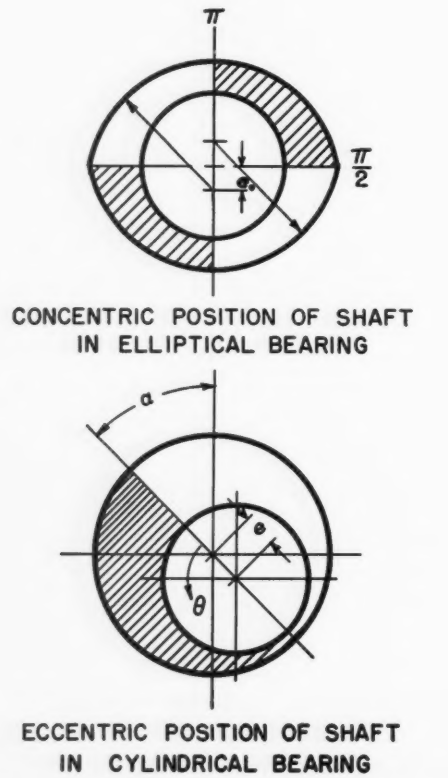


Fig. 3. Relation between cylindrical and elliptical bearings.

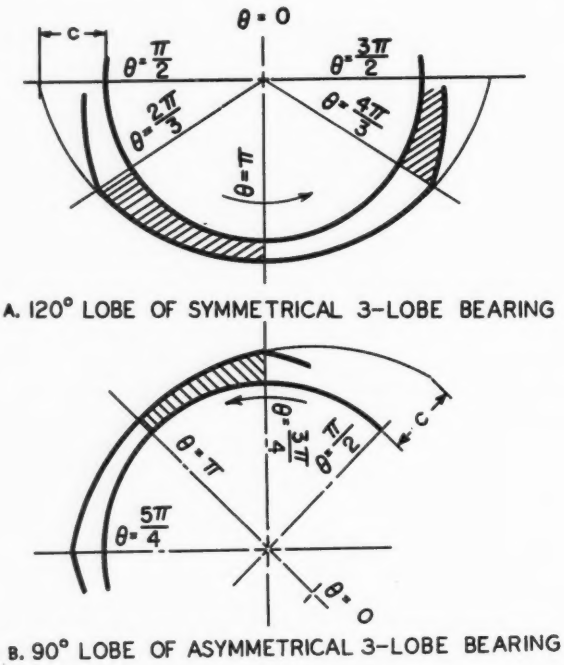


Fig. 4. Elements of three-lobe bearings.

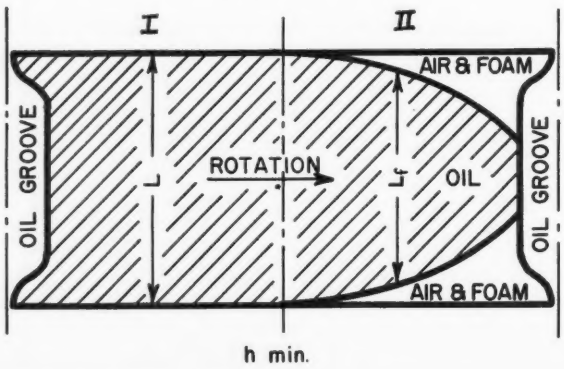


Fig. 5. Incomplete oil film.

$$F = \frac{4ZU^2RL}{\sqrt{c^2 - e_o^2}}\left(\pi - \arctan\frac{\sqrt{3}/2\sqrt{c^2 - e_o^2}}{e_o - 1/2\,c}\right)$$

Dividing out by c and rearranging, the final form is obtained

$$F = \frac{4ZU^2RL}{c\sqrt{1 - m^2}}\frac{3}{2}\left(\pi - \arctan\frac{\sqrt{3(1 - m^2)}}{2m - 1}\right) \tag{12}$$

When $e_o = 0$, the value of Eq. 12 reduces to

$$F = \frac{4ZU^2RL}{c}\frac{3}{2}\left[\pi - \arctan(-\sqrt{3})\right]$$

$$= \frac{4ZU^2RL}{c}\frac{3}{2}\frac{\pi}{3} = \frac{2\pi ZU^2RL}{c}$$

which is Petroff's equation for cylindrical bearings. When $e_o = c$, Eq. 12 gives an infinite power loss.

In practical terms of horsepower, Eq. 12 can be written as

$$H = \frac{1.8\,\mu N^2D^3L \times 10^{-13}}{c\sqrt{1 - m^2}}\left(\pi - \arctan\frac{\sqrt{3(1 - m^2}}{2m - 1}\right) \tag{13}$$

For any given operating conditions and ellipticity ratio e_o/c, the expected power loss in 3-lobe symmetrical bearings can be computed from Eq. 13.

Asymmetrical 3-Lobe Bearing. An asymmetrical 3-lobe bearing consists of an elliptical lower half and of two 90° lobes for the upper half, as shown in Fig. 2. The power losses in the lower half can be obtained by using the formula for elliptical bearings. The analysis of the upper half follows the same pattern as for symmetrical 3-lobe bearings with the exception of the limits of integration. In Fig. 4 the 90° lobe is seen to be contained between the limits of $3\pi/4$ and $5\pi/4$. Writing Eq. 11 only for the upper half we obtain

$$F = 2\int_{3\pi/4}^{5\pi/4}\frac{ZU^2RL}{c + e_o\cos\theta}\,d\theta$$

or since π is a line of symmetry

$$F = 2\int_{3\pi/4}^{\pi}\frac{2ZU^2RL}{c + e_o\cos\theta}\,d\theta \tag{14}$$

Evaluated between these limits, the power losses in the upper half are then given by

$$F = \frac{4ZU^2RL}{c\sqrt{1 - m^2}}\left(\pi - \arctan\frac{\sqrt{1 - m^2}}{\sqrt{2}m - 1}\right) \tag{15}$$

For $e_o/c = 0$ this equation reduces to half the value of Petroff's equation for cylindrical bearings. In terms of practical units, Eq. 15 becomes

$$H = \frac{1.2\,\mu N^2D^3L \times 10^{-13}}{c\sqrt{1 - m^2}}\left(\pi - \arctan\frac{\sqrt{1 - m^2}}{\sqrt{2}m - 1}\right) \tag{16}$$

INCOMPLETE OIL FILM. As pointed out previously, the dimension h in non-cylindrical bearings is

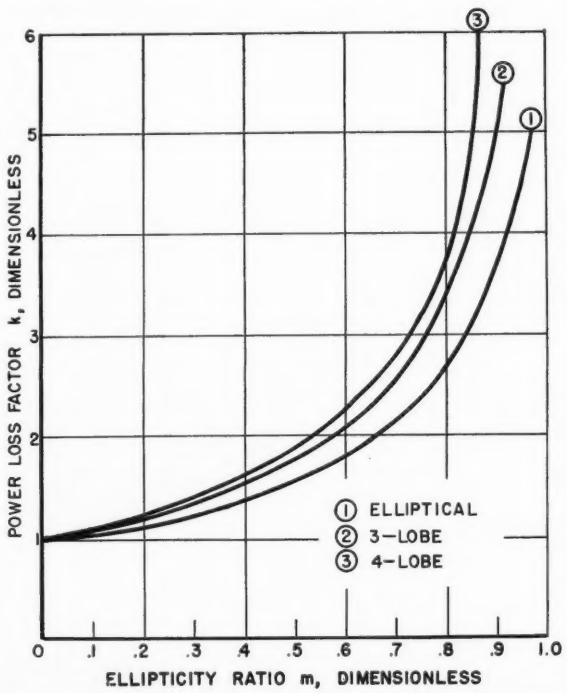


Fig. 6. Ratio of power losses of noncylindrical to cylindrical bearings with complete oil film.

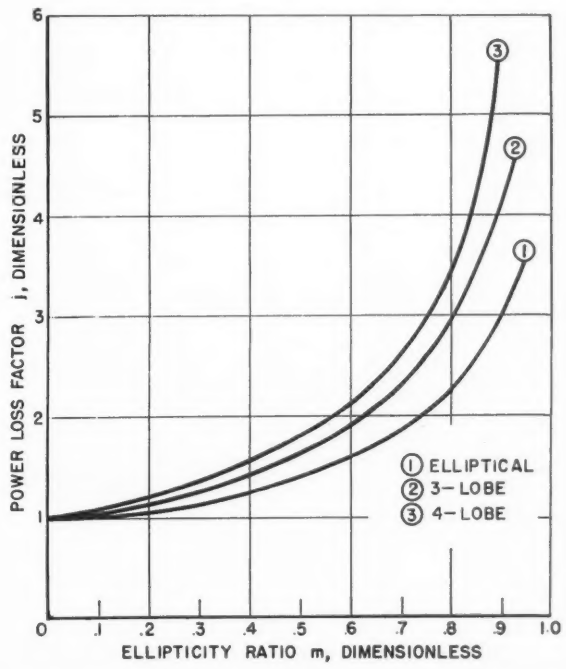


Fig. 7. Ratio of power losses of noncylindrical to cylindrical bearings with incomplete oil film.

a variable even for a concentric shaft position. Most of these bearings are built with oil inlet slots at the ends of the lobes, and a full oil film exists in the clearance space only where it decreases in the direction of rotation since there is not enough oil to fill in the ever-increasing clearance space. Above the point of minimum film thickness the oil film is incomplete throughout the divergent region. The oil film can be considered to break up into streamlets,[2] air and foam replacing the oil in the exposed regions. Presumably no more side leakage occurs, and to satisfy the requirements of continuity the volume of oil must remain constant or

$$L_f \cdot h = \text{constant} \tag{17}$$

from approximately the point of minimum film thickness to the next oil inlet slot. In Eq. 17, L_f is the combined width of the oil streamlets, and is given by the shaded area of Fig. 5.

In section I of Fig. 5 a complete oil film exists, and the power losses are given by the formulae derived in the previous section. In part II we have

$$L_f \cdot h = Lh_{\min} \tag{18}$$

Defining j as the ratio of power loss with incompleteness of the oil film taken into account to that obtained from Petroff's expression, we have

$$j = \frac{H}{H_o} = \frac{\int_0^{2\pi} \frac{ZU^2RL_f d\theta}{h}}{\frac{2\pi ZU^2RL}{c}} = \frac{1}{2\pi}\int_0^{2\pi}\left(\frac{L_f}{L}\right)\left(\frac{c}{h}\right)d\theta \tag{19}$$

From Eq. 18

$$L_f = L\frac{h_{\min}}{h} = L\frac{c(1-m)}{h}$$

Using this in Eq. 19 and defining j_o as the power loss ratio over that portion of a lobe where the oil film is incomplete

$$j_o = \frac{1}{2\pi}\int_{\pi}^{\theta_2}\frac{Lc(1-m)c}{Lh^2}d\theta = \frac{1-m}{2\pi}\int_{\pi}^{\theta_2}\frac{d\theta}{(1+m\cos\theta)^2} \tag{20}$$

Using the substitution

$$\gamma = \arccos\left(\frac{\cos\theta + m}{1 + m\cos\theta}\right)$$

Eq. 20 integrates into

$$j_o = \frac{(1-m)}{2m(1-m^2)^{3/2}}\left\{\arccos\left(\frac{\cos\theta + m}{1 + m\cos\theta}\right) - \sin\arccos\left(\frac{\cos\theta + m}{1 + m\cos\theta}\right)\right\}\Bigg|_{\pi}^{\theta_2} \tag{21}$$

For elliptical bearings $\theta_2 = 3\pi/2$, and Eq. 21 becomes

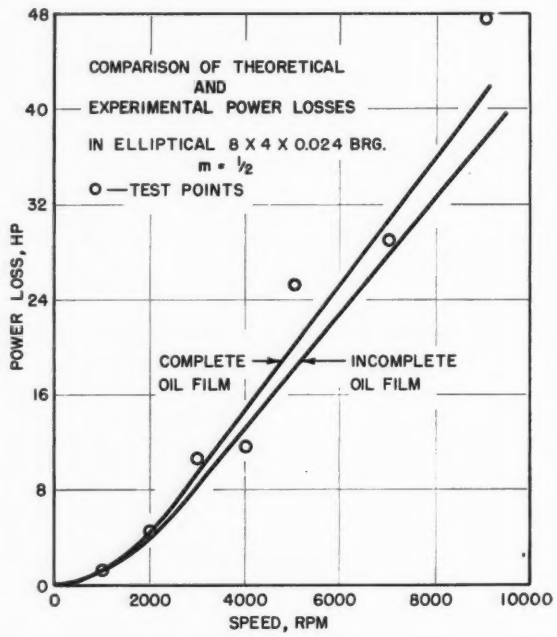


Fig. 8. Power losses in elliptical bearings.

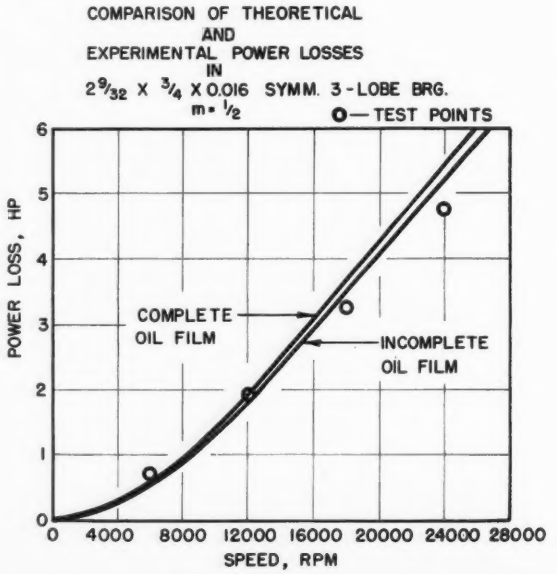


Fig. 9. Power losses in symmetrical three-lobe bearings.

$$j_o = \frac{(1 - m)}{2\pi(1 - m^2)^{3/2}} (\arccos m - m \sin \arccos m - \pi) \tag{22}$$

For symmetrical 3-lobe bearings $\theta_2 = (5/4)\pi$, and Eq. 21 becomes

$$j_o = \frac{(1 - m)}{2\pi(1 - m^2)^{3/2}} \left(\arccos \frac{2m - 1}{2 - m} - m \sin \arccos \frac{2m - 1}{2 - m} - \pi \right) \tag{23}$$

For asymmetrical 3-lobe bearings $\theta_2 = 5/4\pi$, and Eq. 21 becomes

$$j_o = \frac{(1 - m)}{2\pi(1 - m^2)^{3/2}} \left(\arccos \frac{\sqrt{2}m - 1}{\sqrt{2} - m} - m \sin \arccos \frac{\sqrt{2}m - 1}{\sqrt{2} - m} - \pi \right) \tag{24}$$

To obtain the power losses in the portion of the bearing where the oil film is incomplete, Eq. 22 has to be multiplied by 2; Eq. 23 by 3; and for the asymmetrical 3-lobe bearing Eq. 24 has to be multiplied by 2 and added to Eq. 22. For the half where the oil film is complete, the losses are given by one-half of Eqs. 9, 12, and 15.

In Table I and Fig. 6 the power losses in elliptical and 3-lobe bearings, assuming a complete oil film, are presented as a function of the ellipticity ratio m. The

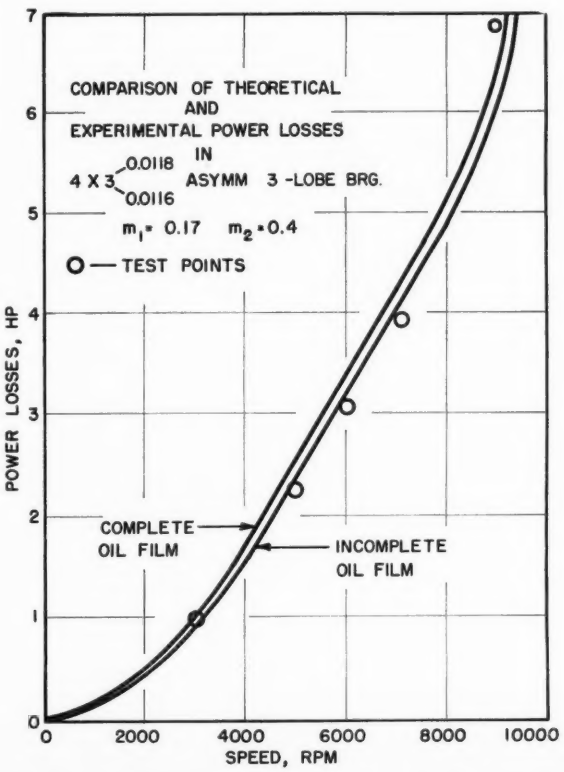


Fig. 10. Power losses in asymmetrical three-lobe bearings.

Table I. Power loss ratio k with complete oil film.

Ellipticity Ratio	Type of Bearing		
	Elliptical	Symm. 3-lobe	Symm. 4-lobe
0.2	1.15	1.20	1.23
0.4	1.38	1.51	1.58
0.6	1.77	2.04	2.24
0.8	2.65	3.34	3.82

Table II. Power loss ratio j with incomplete oil film.

Ellipticity Ratio m	Type of Bearing		
	Elliptical	Symm. 3-lobe	Symm. 4-lobe
0.2	1.11	1.18	1.21
0.4	1.28	1.45	1.54
0.6	1.55	1.88	2.11
0.8	2.19	2.90	3.42

Table III. Comparison of calculated and experimental power losses. Key: (a) Equations 10, 13, 16; (b) Equations 22, 23, 24.

Speed, RPM	Viscosity at Outlet Oil Temp. cps	Power Losses, hp		
		Tests	Calculated Complete Oil Film[a]	Calculated Incomplete Oil Film[b]
Elliptical Bearing, D = 8", L = 4", c = 0.012", m = 1/2				
1000	23.0	1.5	1.2	1.1
2000	22.2	4.6	4.1	3.7
3000	20.5	10.5	9.4	8.5
4000	18.0	11.5	14.7	13.3
5000	17.5	25.3	22.5	20.3
7000	12.0	28.8	30.0	27.1
9000	10.0	47.7	41.5	37.5
Symmetrical 3-Lobe Bearing, D = 2-9/32", L = 3/4", c = 0.008", m = 1/2				
6000	53.0	0.71	0.57	0.55
12000	44.4	1.92	1.90	1.82
18000	37.8	3.25	3.67	3.52
24000	31.8	4.75	5.50	5.28
Asymmetrical 3-Lobe Bearing, D = 4", L = 3", c_1 = 0.006", c_2 = 0.0083", m_1 = 0.17, m_2 = 0.4				
3000	13.3	0.97	.87	0.84
5000	13.8	2.24	2.44	2.35
6000	13.3	3.08	3.40	3.26
7000	11.4	3.94	4.20	4.05
9000	11.3	6.86	6.40	6.15

values represent the ratio of the power losses in the noncylindrical bearings to the cylindrical type having a diametral clearance c. To compute then the power losses in elliptical and 3-lobe bearings, it suffices to compute the losses for a cylindrical bearing of clearance c (the major clearance) using Petroff's Eq. 1 and multiply it by the proper factor k from Fig. 6, or

$$H = kH_o \tag{25}$$

Table II and Fig. 7 give the same results for the assumption of an incomplete oil film. In this case

$$H = jH_o \tag{26}$$

where j is taken from Fig. 7. The column denoted Symm. 4-lobe can be used to calculate losses in an actual 4-lobe bearing. In our case it applies to the upper half of asymmetrical 3-lobe bearings.

Since the value of m in asymmetrical 3-lobe bearings is usually not the same for the upper and lower half, no composite value of k and j can be given for it. To compute the power losses in an asymmetrical 3-lobe bearing, the upper half is treated as a symmetrical 4-lobe bearing and the lower half as an elliptical bearing.

$$H = \frac{1}{2} (k_1 H_{o1} + k_2 H_{o2})$$

or

$$H = \frac{1}{2} (j_1 H_{o1} + j_2 H_{o2}) \qquad (27)$$

where in general $k_1 \neq k_2$, $j_1 \neq j_2$, and $H_{o1} \neq H_{o2}$.

COMPARISON WITH TEST RESULTS. In Table III a comparison is made of the power losses obtained from direct experiments with those calculated from the appropriate equation derived in this paper. The same information is plotted in Figs. 8, 9, and 10. The experiments were conducted on a large Journal Test Stand with a dynamometer housing that enables direct torque measurements.[2] Considering the numerous variables involved in testing bearing performance and the difficulty in obtaining reliable measurements of elliptical and 3-lobe bearings, the agreement between the experimental and theoretical results is very good. The calculated results are not much affected by considerations of an incomplete oil film. At low ellipticities this effect is almost negligible.

In closing, it should be mentioned that the power losses will be higher when the shaft is running at some eccentricity. It is possible to include the effect of eccentricity in the appropriate equations, but to do so requires a knowledge of the locus of shaft center, i.e. the relation between eccentricity and attitude angle. This, in effect, calls for a solution of Reynolds' equation in two dimensions. The analysis presented here is now being extended to obtain such solutions. It is, however, well to remember that 3-lobe and elliptical bearings are used largely in low load applications, and in such cases the equations here derived should prove adequate.

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Cover Story

Examining Crystalline Structure Of A Catalyst. The photograph on the front cover of this issue, taken at Sinclair's Harvey, Illinois, Research Center, depicts a starting point in the research laboratory for the development of petroleum products. The flow of these products to the eventual consumer requires a number of important selling steps by engineers and petroleum salesmen before the product reaches its final destination.

In order for these people to do an effective selling job of products which are highly technical in nature, the petroleum industry necessarily must carry out a concentrated and effective education program. Today the petroleum industry is meeting this challenge by conducting extensive and continuing formal and informal education programs. Among the devices used in such training are special symposiums conducted by research and technical service groups, field meetings on new product development, special technical brochures and publications which cover the basic problems related to specific petroleum products, and general sales manuals which in part provide information on the technique of lubrication.

Millions of dollars are spent each year in furthering education which is vital in preparing oil company representatives to do a competent job of recommending the right product for the right application. This is particularly important in the industrial field where plant management relies to a great extent on the abilities of the oil company representative to assist in attaining maximum operating efficiency at minimum cost.

Typical of training programs being used have been symposiums conducted by Sinclair in training their industrial representatives and lubrication engineers. Recently a two-day session on grease was presented at Sinclair's laboratories; at this meeting research and technical service personnel presented the various aspects of grease technology in a series of planned lectures using visual aids. In addition to the lectures, a tour of the grease laboratory was made. At the end of the session reference material was presented to the people attending so that they would have a permanent record of the material discussed.

Every indication points to a continuing expansion of education within the petroleum industry as the only means of keeping up with advancing laboratory techniques. This problem is not only recognized on an individual basis by the oil companies, but also by various societies and associations directly and indirectly connected with petroleum. Certain chapters of the American Society of Lubrication Engineers have been conducting formalized programs on lubrication. These classes have included studies on the theory of lubrication as well as the practical application of lubricants to industrial equipment.

It is apparent that this is the age of tremendous technical change within the petroleum field. Extensive educational programs will be a must in providing man power with the know-how to do a competent job of assisting the various industries and other types of consumers in solving their lubrication problems. (Submitted by Sinclair Refining Co.)

3rd
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Plant Safety As Related To Lubrication (Panel)

D. W. Dodson, Chrmn.*

At the ASLE 1955 Annual Meeting in Chicago, a panel meeting was held to present the opinions of authorities on the various topics of safety as promoted by the use of (1) fire-resistant hydraulic fluids, (2) centralized lubrication, and (3) lubricants dispensing in press and metalworking operations. Messrs. **W. H. Millett** (Carbide & Carbon Chemicals Co.), **J. D. Lykins** (Wheeling Steel Corp., acting for **J. W. Lander**), and **M. A. Cavanaugh** (The Budd Co.), composed the panel; **Mr. Dodson,** acting for **D. G. Vaughan** (Aetna Casualty & Surety Co.), presided as Chairman.

D. G. VAUGHAN, Aetna Casualty & Surety Co. In discussing the subject of plant safety as related to lubrication, it is not enough to consider conventional grease cups, oil cans, oil drip methods, and usual chassis lubrication procedures. Centralized lubricating systems are vital as means of promoting safety.

In the accident prevention field, reports from all over the country indicate that workmen are injured while climbing ladders to lubricate overhead machinery. When the proximity of workers to operating machinery is reduced by centralized lubrication systems, and safer and more accessible points for applying lubricants, such accidents can largely be prevented.

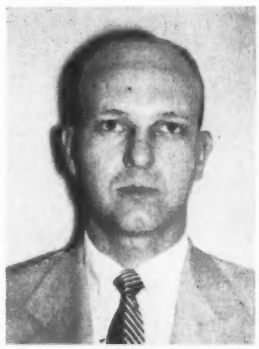
As an added safety factor, machinery should be shut down before being lubricated. Sometimes, however, this is not practicable; sometimes the human error enters when a workman either forgets to shut off the power on the machine, or figures he can save a few seconds and thereby shorten the length of time taken to complete his job. The overhead crane (designed for manual lubrication) is a typical source of accidents occurring during this procedure. In the absence of centralized lubrication, the operator may have to climb all over the crane. If he slips and falls a considerable distance, permanent injury or death can result. Electric shock is another possibility when manual lubrication is required.

Another source of accidents traceable to lubrication, arises through failure to properly lubricate a machine, and the resultant generation of considerable heat. When flammable vapors or an excess of dust exist, an overheated bearing can become a source of ignition to cause a serious fire or explosion. This could happen in a flour mill, a grain elevator, certain chemical plants, a candy factory where there is starch dust, a plastics plant, or any one of a number of similar operations.

Lack of lubrication also can cause a bearing to freeze. This may impose a severe strain on the machine, in some cases resulting in broken shafting and damage to other machine parts. Losses from damaged machinery, spoiled goods in the process of manufacture, and injuries to nearby workmen have all been reported from overheated bearings.

On the other hand, on some types of mechanisms a surplus of oil will cause the excess to spill out. This can set up very serious hazards, i.e., slippery floors from dripped oil, increased fire hazard because of flammable dusts adhering to oil-covered shafts and bearings, excess oil dropping from bearings onto machinery or apparatus where the presence of oil even in small quantities could cause fire or explosions. This could occur in chemical plant nitrators, or elsewhere if flammable vapors are present.

Proper guarding of operating machine parts is an excellent way to forestall accidents. It is quite obvious that there is danger of injury to the man who attempts to oil the bearings of heavy machinery without adequate protection against contact with revolving pulleys, gears, and shafts. Frequently, guards have to be moved in order to reach the oiling points. That is why machinery should be shut down before lubrication is started. When this precaution is overlooked a serious injury may result. In some cases replacement of the guard is forgotten after oiling, another contributing cause of injury to operators.



D. W. Dodson

In safety-conscious plants a foreman or supervisor checks at frequent intervals to see that machines are regularly and properly lubricated, that makeshift ladders are not used, that machinery is shut down for relubrication, and that guards are re-

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placed. In some other plants, especially trained men are designated to inspect the machines just before the shift starts. To offset the chance of injury to mechanics or lubrication personnel, some plants install switches that lock out certain machines. This enables the oiler to cut out and padlock each such section before he works on it. Provided this is done, there is no chance of anyone else starting a machine while it is being lubricated.

On the other hand, there are some machines that must be lubricated manually while they are in motion. To promote safety, service platforms on runways can be built with guard rails and toe boards. Other adjuncts are a small can suspended from overhead, oil reservoirs located at individual bearings, and extension of oil or grease pipes.

Clothing is another factor in connection with safety. It must not be loose, else it might get caught in moving machinery. One-piece overalls are better than two-piece—not so many free edges; sleeves should be kept buttoned around the wrist or cut off above the elbow; trouser legs should not be cuffed but tucked inside wool socks or covered with leggings; gloves should be avoided, neckties or rings should not be worn. Ladder equipment needs special attention.

To summarize, a suggested outline of safety instructions for lubrication personnel is listed. Prominent posting in the plant is recommended.

(1) Clothing should be close-fitting, with no ragged ends; no torn, unbuttoned, or loose sleeves; no loose or torn trouser legs; no long neckties or gloves that might become caught in machinery.

(2) The correct use of ladders and stepladders should be understood, especially the correct way of placing a ladder and length of reach.

(3) The bearings of several countershafts should not be oiled from one position of the ladder. This can involve dangerous reaching.

(4) Stepladders should not be placed astride machinery in motion.

(5) Care should be taken not to walk or stand on machines while they are running.

(6) Idle belts which are hanging about revolving shafting should not be used as supports in reaching bearings.

(7) Reaching over moving pulleys or between moving belts, or using waste or rags to wipe excess oil from moving shafts, are dangerous habits and should be strictly prohibited.

(8) Belts should not be thrown off by hand.

(9) Oil holes in bearings should be kept clean and free from dirt.

(10) The oiler should be careful not to overflow bearings with oil.

(11) The spout of an oil can should be kept clean of dirt particles which might prevent the flow of oil; the result would be dry bearings even though the oiler had supposedly done his duty.

W. H. MILLETT, Carbide & Carbon Chemicals Co., **Improved Safety with Fire-Resistant Hydraulic Fluids.** Any discussion of plant safety as it relates to lubrication is incomplete without some reference to the improvement in over-all safety that can be realized through the use of less-flammable hydraulic fluids. In recent years, engineers who are concerned with safety, lubrication, maintenance, and hydraulics have shown a rapidly growing interest in hydraulic fluids with reduced flammability characteristics. This interest has been stimulated by two factors: first, the recognition that fire-resistant hydraulic fluids mean greater safety; and, second, the development of improved fire-resistant fluids that can be used on a routine basis in industrial installations. These products are of particular interest to anyone using fluids for pressure transfer in hazardous areas, or equipment which is close to potential ignition sources.

It is common practice to refer to fluids of reduced flammability as "nonflammable" hydraulic fluids. This term is actually incorrect, since practically all organic liquids can be made to burn under some conditions. For this reason, these products are more accurately called "fire-resistant," "less flammable," "safety," or "nonflammable-type" hydraulic fluids. The important points to remember are that the fluids now on the market are much less flammable than conventional hydraulic oils, and that they will not burn under the conditions normally encountered in industrial plants.

Original impetus for the development of fire-resistant fluids was supplied by the military during World War II in their search for less-flammable fluids for aircraft. With the cooperation of the chemical and aircraft industries, products were developed that have contributed significantly to aircraft safety. Shortly after the war, several chemical companies undertook projects of making similar products that could be used to meet the somewhat different requirements of industry. As a result of this effort, several types of fire-resistant fluids were developed and are now being used by industry in increasing quantities. Their contribution to safety is unchallenged. Suppliers of fire-resistant hydraulic fluids have in their files records of many instances in which their use has prevented extensive plant damage and injury to personnel.

Fire-resistant fluids that are currently being marketed commercially fall into two broad categories:

1. Aqueous or water-base fluids, which rely on the well-known inertness of water for their fire resistance.

2. Nonaqueous or straight synthetic fluids, which are built around organic compounds that possess inherent flame resistance.

Before a consumer adopts a fire-resistant fluid for any particular application, he should first convince himself that he has a real need for it. Then, if he decides to change over, he should make an honest effort to learn as much as he can about the several types of products and how they differ from conventional hydraulic oils. Safety hydraulic fluids have chemical and physical properties that are different from those of hydrocarbon oils. They behave differently in hydraulic systems. They not only differ radically from conventional oils, they dif-

fer just as radically among themselves. The potential user should become intimately familiar with all of these differences before he puts a fire-resistant fluid into a hydraulic system.

The most important single consideration in the successful use of fire-resistant fluids is maintenance. Plants with good maintenance and housekeeping practices seldom have difficulty in converting to less-flammable hydraulic fluids if they have selected the proper product for their equipment. Clean, tight, well-maintained systems with adequate filtration and moderate temperatures are the basic requirements for success with these products, just as they are with conventional hydraulic oils.

All of the available fire-resistant fluids are excellent solvents or dispersants. They exert a strong solvent or dispersing action on petroleum oil sludges, varnishes, and deposits, as well as a solvent or lifting effect on most of the conventional types of paints used in hydraulic systems. Thus, freedom from fluid contamination becomes an important consideration. Initially, particular care should be taken in cleaning residual oil and sludge from the hydraulic system. Paint that might be affected should be removed from reservoirs. After the fluid is installed filters should be watched carefully, since filter clogging by loosened paint or deposits can cause cavitation and pump starvation. If it is essential to use a painted reservoir, resistance paints are available and can be recommended by the fluid supplier.

In summary, it should be re-emphasized that fire-resistant fluids were developed for a specific purpose—improved safety. They are doing the job for which they were designed, and their use in industrial hydraulic systems should be regarded as safety insurance. They represent a practical answer to a serious safety problem. The best way to succeed in using them is to know what they are, to know how to use them, and to follow sound hydraulic fluid maintenance practices.

J. W. LANDER, Wheeling Steel Corp., **Safety Aspects of Centralized Lubrication.** Our chief observation concerning this subject is the coincident increase in our safety record which has developed since the installation of the automatic centralized lubrication systems, as compared with our experience under the old hand-gun methods of lubrication.

In checking back over the past five years and analyzing our accidents as they related to oiling and greasing operations, it is astounding to find that most of these accidents could have been prevented had our present automatic method of lubrication been in service. In other words, many of our most serious accidents were due to conditions arising from hand methods of lubrication. For instance, several months ago we had a man killed on one of our soaking pit cranes. He was helping change a bearing on the carriage and went to the ground for grease; in returning he slipped off the rail and fell, fracturing his skull. Some other examples will be of interest.

(a) Coal Rig, Coke Plant. On another occasion a coke plant employee was lubricating the trolley on the coal rig and had locked out the switches. When his work was finished he unlocked the switches and gave the craneman the "OK" signal; but for some unknown reason, returned to the top of the crane where he was found minutes later, badly crushed. This crane was, at that time, hand lubricated.

(b) Skullcracker Crane. In this case the employee was assigned to grease gears on the drive, but was warned not to start work until the craneman had finished loading a car. Disregarding instructions, the employee returned to the top of the crane, removed the guard and, as a consequence, was caught and suffered severe head and facial injuries, with permanent impairment of the right eye.

(c) Chipping Building. In still another case, a craneman sent for a maintenance man to check the need for lubrication of the hoist on the crane trolley. He then stepped from the crane cab to go to the top of the crane just as the maintenance man entered the cab. In some unknown manner the control was jogged into an "on" position causing the crane to lurch against the blocks, thus crushing the craneman between the crane cab and a building column.

(d) Finishing Crane Runway. Here an employee was starting to work on a wheel bearing that had burned out, but failed to lock out switch; he had his hand amputated as the crane started in motion while he was holding onto the rail. Carelessness on the part of the injured employee in not locking out the switch, plus the lack of teamwork between him and the crane operator at such times, contributed to another serious accident; but it is a consolation for this safety man to know that we are now in the process of installing centralized grease systems on all overhead cranes and, as a result, the reduction in manual effort and contact will further decrease such injury experience.

(e) Machine Shop. This time an employee attempted to grease a boring mill while it was in operation and while wearing gloves. His glove caught on the drill, resulting in a badly broken hand and wrist which eventually left some degree of permanent disability and disfigurement. The possibility of repetition of this incident has been eliminated by the installation of a circulating oil system.

(f) Skelp Straightener. An employee was greasing the table rolls without shutting down the operation. He thoughtlessly attempted to wipe grease, that he had spilled, off the rolls. In so doing, his hand was caught between the upper and lower rolls, severely crushing the hand and causing amputation two inches above his wrist.

(g) 44" Blooming Mill. Employees were changing a "burned out" table roll bearing as a crane raised the table roll. Employee was attempting to remove bearing when cable broke, permitting roll to fall, thus catching his hand between the roll and bearing. Result: amputated hand. Since the installation of automatic lubrication on this mill about two years ago, we have not had an accident of any type, which is a perfect improvement as com-

pared with our past experience.

(h) Blast Furnaces. Additional improvement in our accident experience is shown in the safety record of our six blast furnaces. Heretofore, it was quite common to have men gassed while in the act of inspecting and lubricating at the top of a blast furnace. This was virtually a daily occurrence, and throughout the steel industry many employees have lost their lives due to working in these gaseous areas, although we have been quite fortunate in this respect.

With the installation of automatic centralized lubrication systems on the blast furnaces, the pumping station and grease reservoir are located at ground level, and the lubricant is piped to the top of the furnace where a measured amount is metered to the individual bearings at specified intervals. This eliminates the daily inspection and manual greasings, and with it the inherent dangers of such assignments. Our present method requires only weekly inspections.

Our safety experience at our Bessemer converters also has improved to a point where we have operated since August, 1953, without an accident; here again, we can point to centralized lubrication as a dominant factor in this favorable development.

(i) Hot Strip Department. Here all table rolls, backup and finishing rolls, screws, coilers, line shafts, and roughing stands are lubricated by an automatic centralized system.

(j) Cold Strip Department. In this department all tandem mills, pickling lines, roller levelers, and shear line also are serviced by a centralized lubricating system.

Because of the nature of the equipment in hot and cold strip operations, it was necessary to halt operations to carry out lubrication under the old manual greasing methods, thereby multiplying, in addition to the hazard, many hours of lost productivity.

In final summation, our experience has proven to us beyond any reasonable doubt that innumerable benefits are derived from centralized lubrication applied to the thousands of bearings and gears, etc., throughout the steel industry, as compared to the old manual-greasing methods. Many of the pertinent hazards that existed under the old system have been eliminated. The insidious problem of dermatitis, which used to be prevalent where an employee was in almost constant contact with oil and grease, also has almost entirely disappeared.

M. A. CAVANAUGH, The Budd Co., **The Significance of "Lubrication."** I wish to take the word "lubrication" and define, by the use of the letters in that word, what I think lubrication means to industry today, and how it relates to safety.

"L" is for Losses. It covers the losses in manhours due to accidents caused by lubrication; it also relates to the losses in profit due to high direct and indirect costs. Naturally, if a machine in the line goes down people have to be sent home. They lose pay, and the company loses the usefulness of that equipment.

"U," the Users. This can be divided into two sections, the first being materials. That comprises, primarily, oils and greases. The other is the type of systems in use. These involve oil cups, grease cups, shielded bearings, mist systems, one-shot lubrication systems, timed lubrication, and central lubrication systems. Not too many years ago when we bought a piece of equipment, it was equipped with grease guns, grease fittings, or oil cups. We all had quite a time selling management on doing away with this type of equipment. Industry as a whole enlisted the services of the lubrication equipment companies to promote more modern ways of lubrication. What has been the result? The mist system, one-shot, and centralized lubrication; also, now, the timed type of lubrication.

"B"is for Bearings. The modern theory is to build the proper type of bearing into the equipment for the application under which it is to be used.

"R" is for Recommendations. These should be handled between a lubrication engineer, a chemist, and the purchasing department, preferably in that order. Don't let the purchasing agent sell you something because he can get it for five cents cheaper than what you should have. You buy a piece of equipment from a manufacturer who often specifies the type of oils and greases he considers should be used. On the other hand, from that standpoint you can have too many different types of lubricants, the result being that eventually the wrong type of lubricant may get into some units. Try to standardize your lubricants as much as possible, working in conjunction with the equipment builder and the lubrication companies you deal with.

"I" is for Indicators. Those are sight glasses, levels, relief valves, the use of color schemes for indicating points for lubrication, and the frequency of lubrication. If possible, charts should be mounted with the equipment, and the manuals issued by the equipment manufacturers should be read and followed.

"C" is for Cleanliness. Cleanliness has to do with the proper storage and dispensing of greases and oils. Another factor that concerns us is deterioration and contamination. There is nothing more unsightly than a piece of equipment covered with oil and grease to the point of dripping. Obviously, this involves a hazard.

"A" is for Accessibility. This has a two-fold relation; first, from a personnel standpoint. If lubrication facilities are accessible, hazards will be reduced. Second, if parts are accessible you can be sure the machine will be lubricated.

"T" is for Time. Lubrication should be scheduled either by the shift, the day, the week, the month, or the year, whichever is the necessary time for the particular point to be lubricated. In this connection, we regard timed lubrication as particularly applicable to press equipment. This is adjusted so that every five minutes, every fifteen minutes, or whatever time you want to set, a shot of lubricant is delivered to all points of that particular piece of equipment. Here you eliminate having to depend upon a person to do it at a scheduled time.

"I" is for Instruction. Instruction should be given to the maintenance supervision, the mechanics and the oilers of the maintenance division. It should also be given to your production supervisor, and, certainly, the operators of the equipment should be aware of all points requiring lubrication on their equipment. This is one of the chief ways in which lubrication enters into a preventive maintenance program. Furthermore, your oilers, electricians, millwrights, and people of that nature who work on such equipment, should be instructed that the first thing they should do is to shut down the machine before they start to work on it. This cannot be stressed too highly from a safety standpoint.

"O" is for Observation. The majority of us have five senses. You can observe your lubrication through your eyes, your ears, your nose, and, let us say, even through your mouth by the taste of the oils or greases, and through your hands, in the old-fashioned way of determining whether the oil is good. You should go further than that and periodically test your lubricants. A lot of the machines today are equipped with a central lubricating system from which lubricant (either oil or grease) is pumped to the different points to be lubricated. Where oil is involved it should be periodically tested and filtered to insure quality and absence of non-lubricating contaminants.

"N" is for Notes or Records. We cannot stress too highly the benefit of keeping accurate records. Those should include the frequency, the quality, the quantity, and the cost of both labor and material. In small companies, that may not be too easily done. Even so, records have a great deal of bearing on the matter. You can use them in the event of trouble with the manufacturer of a piece of equipment—you can prove your point; and if you can do it, you won't have too much trouble in getting them to redesign parts or furnish other parts because of the failures. In my company we expect our supervisors to talk to two, three, or four men every day on safety angles. If you get your supervisors talking safety to the men, you will find that your entire operating personnel will become so safety conscious after a while that they will constantly be thinking and acting safely.

QUESTIONS & ANSWERS

Q. Are fire-resistant hydraulic fluids being used or considered to operate coke oven equipment?

A. At the present time we are using fire-resistant hydraulic fluids for lubrication of the door pushers on the coke ovens, on the controls on the soaking pits and open hearths, with very good results. (Lykins)

Q. Are water-base hydraulic fluids useable at temperatures as low as minus 65 degrees Fahrenheit?

A. Industrial-type fluids which are used in such equipment as die casting machines, welding machines, and presses, are not designed for —65 F. operation. However, water-base hydraulic fluids currently being used in naval aircraft are designed specifically for low-temperature operation; they have a viscosity of approximately 2,000 centistokes at minus 65. (Millett)

Q. What types of filters are recommended for use with water-base fluids; and should they be used as full-flow filters or otherwise?

A. In general, practically any type of filter medium, with the exception of Fuller's Earth or activated clay, is satisfactory. The latter are not recommended, since they tend to remove the additives from the formulation. Probably the most successful types are the cellulose cartridge filters and the metal screen devices. Paper filters sometimes tend to clog if there is an appreciable amount of contamination in the hydraulic system, and in some instances fluids have shown an adverse effect on the resin binders used with these filters.

Filters in hydraulic service can be used either as full-flow or by-pass. Many users find it very satisfactory to have an auxiliary portable filter which can be moved from machine to machine. In this way, auxiliary filtering is going on all the time as the filter is rotated from one system to another. (Millett)

Q. How about corrosion resistance, particularly as applied to the water-base fluids; also to vapor-phase corrosion, and a comparison between fire-resistant fluids and petroleum oils?

A. Since my connection has primarily been with water-base fluids, I feel most qualified to discuss that type. With any system comprising from 35 to 50 percent water, corrosion can be a problem. Naturally, this has concerned the people who have developed these fluids, and you can be sure that a tremendous amount of work has gone into the formulation of these products, one of the key objectives being the incorporation of effective aqueous corrosion inhibitors for both the liquid and vapor-phases. The background in this field of development is very similar to the work done on anti-freezes for automotive cooling systems.

Corrosion has not been a problem with the use of water-base fluids industrially, although occasionally we run into corrosion problems where there has been contamination. For example: In hydraulically-operated furnace combustion controls in steel mills, there is frequent regulation of the rate of gas flow or adjustment of the fuel-air ratio. This gas is sometimes high in sulfur content, and under those conditions vapor-phase corrosion may be a problem. Vapor-phase corrosion inhibitors minimize this to acceptable low levels, in some cases even completely eliminating the trouble. Although vapor-phase corrosion has not been found to be a problem in the vast majority of hydraulic systems, it is certainly more apt to occur with aqueous fluids than with petroleum oils. With proper attention to design and maintenance considerations, it can usually be avoided. (Millett)

A. I would like to make a comment on type of filters recommended. In the use of cellulose filters, there is one thing that you should consider seriously, and that is that all the cellulose-type filter elements are not treated to make them water-resistant. As a result, we had some sad experience at first where the filter element disintegrated. Today, all of our filter elements are now backed with either felt or a canvas-type material, so that if we do encounter a unit that would tend to disintegrate, the contents are kept from getting out to the system. (Lykins)

Q. Has nylon tubing been used on central systems? What are the results?

A. We have not used any nylon tubing on our centralized grease systems. However, we have had very good results with nylon tubing on oil-mist or fog systems where the pressures have not been too high and the temperatures are no criterion. (Lykins)

Q. Relating to the general subjects of lubricating characteristics, the lubricity of fire-resistant fluids, and how they compare with each other, and petroleum oils, is the

type of system a factor?

A. Lubricity and corrosion are the two factors that have received the most attention. In our own laboratories we have set up a standard series of tests which are run on development formulations, on our standard fluids, and on our competitor's products. This procedure has been found to be a very effective means of measuring the lubricating characteristics.

The test rig involves a vane-type circulating pump with a relief valve, sump, filter, coolers, and flow-meters, all incorporated in the system. Several different types of tests can be run on this very flexible unit. The effect of discharge pressure can be determined by running fluids over a range of pressures. A long-term endurance test will give an excellent idea as to how the fluid could be expected to stand up in service. A short-term test procedure of 40 hours' duration is used with the same equipment to get an indication as to wear characteristics.

Long-term tests on water-base fluids have indicated that wear is in the same general range as obtained with high-quality, petroleum-type hydraulic oils. Variation from oil to oil of the conventional type is probably greater than the deviation between water-base fluids and the petroleum products designed for this type of service.

Since water-base fluids contain from 35 to 50 per cent water, they are not generally recommended for high-temperature service due to the high-vapor pressure of water. These products should not be used if bulk fluid temperatures are in excess of 150 F. In fact, it is sound hydraulic practice to keep fluid temperatures within a range of 110 to 130 F., regardless of the type being used. Viscosity is a very convenient means of measuring water content. As you lose water the viscosity increases. Many plants have set up a system of periodic measurement of the viscosity in order to determine the water content, or the extent of water loss. During the initial period of operation it is well to measure the viscosity frequently, say once a week, in order to get the pattern and find out if there are any peculiarities in the system to cause excessively high water loss. After having established the pattern, viscosity controls can be run less frequently, say every three or six months.

The type of pump, of course, is a factor. Some types are much more critical than others with respect to lubrication, so the problem usually must be handled on an individual basis.

The effect of fire-resistant hydraulic fluids on seals, packings, and hose also must be studied. Here there is a real difference between water-base and nonaqueous types of such products. In general, water-base fluids do not adversely affect the types of rubber that are conventionally used with petroleum oil.

When fire-resistant fluids were first used, steel deterioration was quite a serious problem because all the angles were not known. Today, it is not too serious a matter. It merely requires the use of a suitable resistant-type of seal in accordance with the type of fluid. (Millett)

Q. How do you grease open gears on cranes?

A. At the present time we are in the process of installing automatic centralized equipment. It used to be customary to either brush the lubricant onto the open gears, or to use hand spray guns; today, we feel that the spray application has been developed to the point where we can go ahead with it now and improve the application considerably. (Lykins)

Q. Do you use oil or grease in centralized systems?

A. Depending on what we are lubricating, we have equipment which can be considered as centralized lubrication equipment for oils, although grease is the preferred lubricant for cranes. (Lykins)

Q. Is it correct to presume that aqueous-type hydraulic fluids are not recommended for hydraulic pressures in excess of 1,000 psi?

A. It is incorrect. Many systems are operating at pressures of 1,500 pounds with 1,000-pound pumps; others involve the use of 2,000-pound and 2,500-pound pumps. (Millett)

Q. How about the explosion hazards of ordinary hydraulic fluids due to leaks or air in the system under the usual operating pressures?

A. We know there are hazards. Wherever a fluid is being moved, or is being used to move equipment operating under pressure, any small leak in the system under the prevailing pressure will cause a spray of fluid. Sometimes those sprays travel astoundingly great distances—50 to 60 feet—to contact some source of ignition such as molten metal in the die casting industry, a hot ingot, or any material that might flash a flammable fluid. Unfortunately, it is a flash fire. You do not have time to get out of the way. Fire-resistant fluids are designed to overcome this difficulty. (Millett)

Q. Do plastic molding machines warrant the use of non-flammable-type hydraulic fluid?

A. This is a new field which is being investigated. The City of Los Angeles, where a lot of plastic molding is done, is particularly concerned about this.

It should be stated that, initially, the principle emphasis was directed toward the die casting industry. Here there was a known hazard. Fires had occurred which had been accepted as routine in such plants. Fire-resistant fluids were developed with this industry in mind, but with the successful use of these materials in die casting, their use has been extended to welding machines, presses, and other types of equipment in various industries. Recently, discussions have been devoted to fire-resistant steam turbine oils.

As to the application of water-base fluids in air compressor lubrication systems, here the temperatures which prevail are probably too high for a water-base type product, in view of the potential explosion hazard which exists where two-stage or three-stage compressed air is used for starting gasoline engines. (Millett)

Book Reviews

Basic Lubrication Practice, by A. F. Brewer; Reinhold Publishing Corp., New York, 1955; 286 pages, extensively illustrated, price $6.75. (Reviewed by K. H. Strauss, The Texas Co.)

Based on his extensive experience in the field of industrial lubrication, the author has compiled a handbook of lubrication practice. Starting with a discussion of operating conditions and their general effects on lubricant performance, he then deals with the more common inspection tests performed on lubricants and greases. Various types of bearings and bearing materials are covered in detail. Plain bearing design is discussed from the practical point of view, while the section on ball and roller bearings is concerned mostly with lubrication and maintenance procedures. Photographs of typical failures and their causes are included. A section on gears is devoted mostly to the recognition and prevention of various types of failures. Other chapters deal with chain and wire rope lubrication, flexible couplings, seals, and automatic lubrication. Lubrication recommendations are included in the different sections.

The second part of the book treats general types of lubrication

(Continued on p. 152)

A Mass & Energy Balance For The Wear Process

by P. F. Chenea* & A. E. Roach**

A mathematical treatment is given of one phase of the wear processes which is defined as "fatigue wear." This wear is envisioned as a sink for energy after a disturbed surface has become saturated with internal energy, that is, has become work hardened to the limit, and the additional energy is used to increase the surface area (produces abraded particles). A mass and energy balance is presented to describe the process.

Several types of wear have been distinguished in the literature. These include adhesive wear, resulting from metal transfer and pick-up between surfaces in sliding contact; abrasive wear, resulting from either the ploughing of a soft surface by the asperities of a hard surface or the cutting action of loose abrasive material between the sliding surfaces; corrosive wear, resulting from chemical attack of either or both of the sliding surfaces; and fatigue wear, resulting from repeated stressing of the contacting surfaces due to relative sliding. The present paper is concerned primarily with wear of the last-mentioned type.

Fig. 1 shows a "wear" track left on an iron plate by an iron stylus. The plate was finished by unidirectional polishing on abrasive paper; the finishing marks are visible as vertical lines in the figure. The "wear" track produced by a single passage of the stylus over the plate is visible as a group of irregular horizontal marks crossing over the finishing marks.

The principal feature to be noted in Fig. 1 is the severity of plastic deformation (smearing of metal) in the "wear" track. Even on a microscopic scale, the extent of the damage in the track is enormous. Such deformation, if carried out repeatedly, as, for example, by reciprocation of the stylus upon the plate, will be accompanied by an increase in internal energy which will be manifested as strain hardening.

Eventually the disturbed surface layer will become saturated with internal energy (strain hardened to the limit). If the surface is then further deformed, the additional work input can no longer be stored as internal energy. It must either be dissipated as heat or appear in some new form. One form in which it may appear is as an increase in free surface energy through the generation of wear particles.

Although the laws governing the generation of wear particles are not known in sufficient detail for a complete analysis of the process, enough is known for a mass and energy balance. The results of this mass and energy balance disclose several features of interest to students of wear.

MASS BALANCE. Consider a surface undergoing wear, as indicated by Fig. 2. Here h is the total change in surface level due to sliding contact with another surface which is not shown. Part of h is caused by "wear" (that is, by removal of material as wear particles) and part by a change in density of a disturbed surface layer of thickness H.

Let ρ_o be the original density of the surface material, ρ_w the mean density of the wear particles, and $\rho_D(z)$ the density of the disturbed layer as a function of depth z.

For unit area of surface, the mass of the original surface layer is $\rho_o(h + H)$, the mass of the remaining surface layer is $\int_0^H \rho_D(z)dz$, and the mass carried away by N wear particles is $\sum_{i=1}^{N} m_i$, in which m_i is the mass of the ith wear particle.

If it is assumed that the number of wear particles is so large that their size distribution may be represented by a frequency function $p(m)$ such that $p(m)dm$ is the probability that an arbitrary wear particle will have a mass between m and $m + dm$, then the

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mass carried away by the wear particles is simply

$$N\int_0^\infty mp(m)dm.$$

The mass balance for one surface (denoted by subscript 1) may now be written as

$$\rho_{o1}(h_1 + H_1) = \int_0^{H_1} \rho_{D1}(z)dz + N_1 \int_0^\infty mp_1(m)dm \qquad (1)$$

while that for the other surface (subscript 2) is

$$\rho_{o2}(h_2 + H_2) = \int_0^{H_2} \rho_{D2}(z)dz + N_2 \int_0^\infty mp_2(m)dm \qquad (2)$$

ENERGY BALANCE. When two bodies are rubbed together, work must be done to overcome sliding friction. This gives rise to an increase in temperature at the interface where the bodies are in contact. In addition, there will be, as we have seen, plastic deformation of the surface layers of the bodies and, hence, an increase in their internal energy. If wear occurs, as it inevitably will, there will be an increase in surface-to-mass ratio as a result of the generation of wear particles. When the wear particles leave the surface, they will carry a certain amount of heat and internal energy away with them.

For this simplified model of the wear process, the law of conservation of energy gives rise to the following energy balance: Mechanical power input = rate of heat flow into body being worn + rate of increase of internal energy in disturbed surface layer + rate of increase of surface energy by generation of wear particles + rate of heat transport by wear particles + rate of internal energy transport by wear particles.

This may be written as:

$$fPV = \left[K_1 \frac{d\theta_1(z)}{dz} + K_2 \frac{d\theta_2(z)}{dz} \right]$$

$$+ \left[\frac{d}{dt}\int_0^{H_1} \epsilon_1(z)dz + \frac{d}{dt}\int_0^{H_2} \epsilon_2(z)dz \right]$$

$$+ \left[a_1 S_1 \frac{dN_1}{dt}\int_0^\infty \left(\frac{m}{\rho_{w1}}\right)^{2/3} p_1(m)dm \right.$$

$$\left. + a_2 S_2 \frac{dN_2}{dt}\int_0^\infty \left(\frac{m}{\rho_{w2}}\right)^{2/3} p_2(m)dm \right]$$

$$+ \left[c_1(\theta_{w1} - \theta_{o1}) \frac{dN_1}{dt}\int_0^\infty mp_1(m)dm \right.$$

$$\left. + c_2(\theta_{w2} - \theta_{o2}) \frac{dN_2}{dt}\int_0^\infty mp_2(m)dm \right]$$

$$+ \left[\epsilon_{p_1} \frac{dN_1}{dt}\int_0^\infty mp_1(m)dm \right.$$

$$\left. + \epsilon_{p_2} \frac{dN_2}{dt}\int_0^\infty mp_2(m)dm \right] \qquad (3)$$

in which the subscripts 1 and 2 refer to the separate bodies participating in the wear process, and

f = friction coefficient, dimensionless
P = normal load, dynes per cm²
V = sliding velocity, cm per sec
K = thermal conductivity, dyne-cm per cm per °C per sec
$\theta(z)$ = temperature at depth z below worn surface, °C
$\epsilon(z)$ = internal energy density increase at depth z below worn surface, dyne-cm per cm³
N = number of wear particles removed per unit area of surface, cm⁻²
a = shape factor for wear particles (ratio of area to two-thirds power of volume), dimensionless
S = surface energy per unit area of wear particles, dyne-cm per cm²
o = heat capacity per unit mass of wear particles, dyne-cm per °C per gm
θ_w = mean temperature of wear particles, °C
θ_o = initial temperature, °C
ϵ_p = internal energy per unit mass of wear particles, dyne-cm per gm

Steady-State Mechanical Wear Between Identical Materials. If steady-state conditions prevail, the depth of the disturbed surface layer will be con-

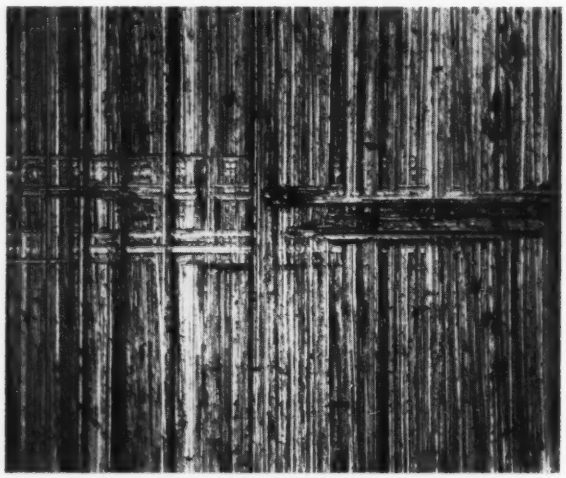

Fig. 1. Wear track on iron plate.

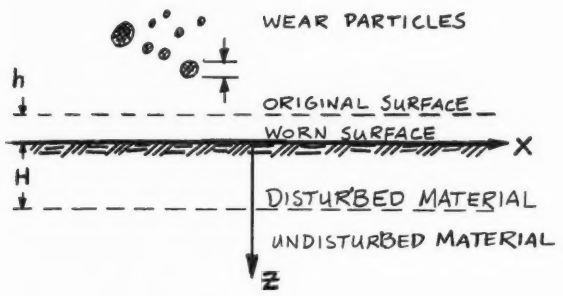

Fig. 2. A surface undergoing wear.

stant and the change in internal energy may then be taken as zero. If the surfaces are of identical materials, the work input may be assumed to be divided equally between them. Hence, for a single surface Eq. 3 becomes

$$\frac{1}{2} fPV = K \frac{d\theta(z)}{dz} + \alpha S \frac{dN}{dt} \int_0^\infty \left(\frac{m}{\rho_w}\right)^{2/3} p(m)\,dm + c(\theta_w - \theta_o) \frac{dN}{dt} \int_0^\infty m p(m)\,dm + \epsilon_p \frac{dN}{dt} \int_0^\infty m p(m)\,dm \qquad (4)$$

If changes in density are negligibly small, so that $\rho_D = \rho_w = \rho_o = \rho$ approximately, then for a single surface Eqs. 1 & 2 become

$$h = N \int_0^\infty \frac{m}{\rho} p(m)\,dm$$

or

$$\frac{dh}{dt} = \frac{dN}{dt} \int_0^\infty \frac{m}{\rho} p(m)\,dm \qquad (5)$$

Eliminating dN/dt between Eqs. 4 & 5 and solving for dh/dt, one obtains

$$\frac{dh}{dt} = \frac{\frac{1}{2} fPV - K \frac{d\theta(z)}{dz}}{S \left\{ \frac{\alpha \int_0^\infty \left(\frac{m}{\rho}\right)^{2/3} p(m)\,dm}{\int_0^\infty \left(\frac{m}{\rho}\right) p(m)\,dm} \right\} + \rho \left[c(\theta_w - \theta_o) + \epsilon_p \right]} \qquad (6)$$

Here the numerator represents the power unit area available to activate the wear process, while the denominator represents the inherent wear resistance of a unit area of surface. This wear resistance is undoubtedly related to the hardness or mechanical strength of the material.

It is well known that the two terms in the numerator of Eq. 6 are very nearly equal. Consequently, small changes in either of them may give rise to very large changes in the rate of wear. This is the principal reason for the notoriously poor reproducibility of wear experiments.

Isothermal Steady-State Wear Between Identical Materials. If wear occurs isothermally, Eq. 6 becomes

$$\frac{dh}{dt} = \frac{\frac{1}{2} fPV}{\frac{S}{l} + \rho\epsilon_p}$$

in which $1/l$ represents the term enclosed in braces in Eq. 6. An equation of this type has been proposed by Holm[1] and discussed by Burwell and Strang,[2] and by Archard.[3] As might be expected, it is necessary to introduce a very small coefficient on the right side in order to obtain reasonable agreement with experimental data.[4]

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ACKNOWLEDGEMENT. Grateful acknowledgement is made for the continued support and encouragement of Messrs. A. F. Underwood and J. B. Bidwell of General Motors Corp.

Current Literature

New Lining Material. A bulletin describing a new lining material that can be applied to inexpensive containers, tanks, pipes, etc., making them lighter than, superior to, and less expensive than, costly alloy metals is offered by The Garlock Packing Co., Palmyra, N. Y. The lining material is a laminate of Kel-F plastic fused and flowed into a glass fiber cloth backing. Conventional adhesives can be used to apply the laminate to practically any contoured surface, and it can be applied to large tanks and vessels right on-the-job without moving them to an applicator's shop.

Revised Data Sheet Numerical Index. The National Standards Committee of ASTE has just announced publication of a revised Data Sheet Numerical Index, adapted from the U. S. Standard Commodity Classification Sys-

(Continued on p. 152)

Pittsburgh's Golden Triangle

Welcome!

W. Deutsch (The Aro Equipment Corporation), ASLE President-Elect for 1956-57.

L. B. Sargent, Jr. (Aluminum Co. of America), Chairman of the ASLE Pittsburgh Section.

ASLE 11th Annual Meeting & Exhibit

Hotel William Penn, Pittsburgh, April 4-5-6, 1956

On behalf of the Officers & Directors of the American Society of Lubrication Engineers, welcome to the 11th Annual Meeting & Exhibit. We feel certain that each member, guest, and the companies they represent, will find the program and exhibits have been well worth the time and expense to attend. The National Program Committee, working with the Technical Committees, has arranged an excellent program of the foremost speakers representing the practical as well as the theoretical approach to the lubrication science. The exhibits represent the latest products and equipment available to modern industry. We are indebted to the Regional Vice-Presidents, to the Pittsburgh Section, and to the Ladies' Program Committee for their work in making the non-technical portions of the meeting both interesting and enjoyable to the members, guests, and the wives. The success of the 11th Annual Meeting has been possible through the unselfish contributions of many people. We sincerely hope you have been pleased with the results of these contributions, and that they have helped make each of you better qualified to carry out your respective lubrication assignments. We further hope that you will plan now to join us again next year for the 12th Annual Meeting in Detroit.

W. Deutsch

On behalf of the Pittsburgh Section, a most hearty welcome is extended to the 11th Annual Meeting of the American Society of Lubrication Engineers. As your host, we are looking forward to making your visit a most enjoyable and pleasant one. Those of us who have worked toward this end believe that the series of programs will be suitable for all who attend.

Pittsburgh people were very active in the early formative years of ASLE, and have continued in the forefront since then. The high concentration of metal-working industries in this area has furnished a corps of people whose needs are being met by ASLE. This steel capitol of the United

States recognizes the urgency and importance of the problems with which the membership of ASLE is concerned.

Your host Section is proud to be able to welcome you to a city reborn; to a city whose efforts in the past few years to eliminate unsightly blighted areas, to eliminate a smoke nuisance, and to create bold designs in construction, have attracted the attention of the entire nation. You will be pleased at the results of our efforts in creating a Point Park, a Gateway Plaza, stainless steel-clad buildings, aluminum-clad buildings, an educational and medical center, and new industrial research centers. Pittsburgh is second to none in steel-making, medical research, and industrial research. During your stay with us, we hope you have a chance to see and visit some of these.

We sincerely trust that you will enjoy your visit to Pittsburgh, and that the 11th Annual Meeting will be a pleasure and worth the time and effort which you all will make to be with us.

L. B. Sargent, Jr.

D. W. Sawyer (Aluminum Co. of America), Chairman of the ASLE National Program Committee.

On behalf of the National Program Committee, we are certainly most happy to welcome you to the 11th Annual Meeting & Exhibit of the American Society of Lubrication Engineers. Our Committee has planned a series of papers of outstanding calibre, arranged in unified sessions, and balanced to suit the needs of all. It is hoped that each of you will find this meeting both profitable and enjoyable.

We of the National Program Committee wish to express our many thanks to the various Technical Committee session organizing chairmen, and papers representatives, for their fine cooperation in the planning and organizing of the technical sessions.

D. W. Sawyer

Mrs. John Boyd, Chairman of the Ladies' Program Committee.

The Pittsburgh Section of ASLE welcomes the wives and guests attending the 11th Annual Meeting, and has planned a program to make their visit both interesting and entertaining.

Registration for the wives will be held Wednesday morning, and the first activity will be luncheon, noon Wednesday, at The Carlton House, one of Pittsburgh's newest and most elaborate apartment hotels. Following the luncheon, we have scheduled a three-hour tour to include many highlights of the Pittsburgh area such as the Gateway Center, the Block House (Old Fort Duquesne), Mt. Washington, a ride on one of Pittsburgh's inclines, Oakland Civic Center, Schenley Park, the Mesta Mansion, Highland Park, North Side, Buhl Planetarium, and West Park.

Thursday's activities will begin with a tour of the H. J. Heinz Plant. There we will be shown how many of the famous Heinz products are manufactured, including: soup, spaghetti, mustard, beans, vinegar, and pickles. The ladies will have an opportunity to sample some of the well-known 57 Varieties.

Luncheon on Thursday will be held at the Horizon Room of the new Greater Pittsburgh Airport. After lunch, we will take a guided tour of the airport and be shown many of the behind-the-scenes activities of one of the largest and finest airports in the country.

On Friday morning a rare opportunity to visit one of Pittsburgh's great steel mills will be provided. The tour will include

Meeting of ASLE Board of Directors in Pittsburgh, January 19. Seated, from left to right: A. E. Cichelli (Director), Bethlehem Steel Co.; W. P. Youngclaus, Jr., ASLE Administrative Secretary; E. R. Booser (Secretary), General Electric Co.; J. Boyd (Chrmn., Presidential Council), Westinghouse Research Labs.; W. H. Fowler, Jr., (Treasurer), The Pure Oil Co.; J. W. Hopkinson (President), Penn-Petroleum Corp.; W. Deutsch (Vice-President at Large), The Aro Eqpt. Corp.; W. H. Millett (Director), Carbide & Carbon Chemicals Co.; R. H. Josephson (Director), Cleveland Graphite Bronze Co.; C. R. Schmitt (Director), E. F. Houghton & Co. Standing, from left to right: J. D. Lykins (Director), Wheeling Steel Corp.; J. O. McLean (Eastern Vice-Pres.), Reynolds Metals Co.; E. D. Harkins, Sr. (Midwestern Vice-Pres.), The Farval Corp.; J. L. Finkelmann (Director), The Warren Refining & Chemical Co.; J. H. Fuller (Director) E. I. duPont deNemours & Co., Inc.

the open-hearth department of the Jones & Laughlin Steel Corporation. Low-heeled shoes and tailored clothes must be worn for this tour.

No formal arrangements have been made for lunch on Friday. In the afternoon, a tour of the Nationality Rooms at the University of Pittsburgh has been scheduled.

Mrs. John Boyd

National Program Committee. Seated, from left to right: C. R. Lewis (Standard Oil Co.), Vice-Chairman; D. W. Sawyer (Aluminum Co. of America), Chairman; J. W. Hopkinson (Penn-Petroleum Corp.), ASLE President. Standing, from left to right: J. P. Critchlow (Gulf Oil Corp.), National Meeting Chairman; L. B. Sargent, Jr. (Aluminum Co. of America), Pittsburgh Section Chairman; W. P. Youngclaus, Jr., ASLE Administrative-Secretary.

"Opportunity Knocks for Lubrication Engineers," by DeLoss Walker (pictured above), Guest Speaker for the ASLE Annual Meeting Banquet. Mr. Walker, internationally-known analyst and interpreter of economic trends, outspoken champion of productivity, and forceful exponent of constructive action, has a message to help you obtain the opportunities here today . . . action each Lubrication Engineer can take to attain his personal goal. Mr. Walker's background, after graduating from DePauw University (Greencastle, Ind.), includes work in China for the Chinese government, the operation of his own coal mines, presidency of a sales corporation, and government service in the War Production Board during World War II. He has been a contributor to various publications, and for several years was Associate Editor of "Liberty" magazine.

Pittsburgh Annual Meeting Committee. Seated, from left to right: A. A. Raimondi (Arrangements Chrmn.), Westinghouse Research Labs.; D. W. Howard (Publicity Chrmn.), Gulf Research & Development Co.; J. P. Critchlow (Chairman), Gulf Oil Corp.; Mrs. John Boyd, Ladies' Program Chrmn.; G. L. Sumner, Jr. (Reception Chrmn.), Alemite Co. of Pittsburgh; M. Parker (Treasurer), E. F. Houghton & Co. Standing, from left to right: W. P. Youngclaus, Jr., ASLE Administrative Secretary; D. W. Sawyer (National Program Chrmn.), Aluminum Co. of America; W. L. Cowan (Vice-Chrmn.), American Oil Co.; L. B. Sargent, Jr. (Pittsburgh Section Chrmn.), Aluminum Co. of America; J. D. Lykins (Exhibits Arrangements Chrmn.), Wheeling Steel Corp.

Section News

BUFFALO, November '55 meeting. D. A. Hall, Lubrication Engineer for Eastman Kodak Co., presented a paper entitled "What ASTM Means to ASLE."

February. "Fuels & Lubricants for Plant Lift Trucks," by N. T. Brenner, Product Application Engineer of the Gulf Oil Corp.

March. "Plane Bearing Design & Lubrication," by D. W. Spaulding, Application Engineer of Bunting Brass & Bronze Co., Inc. (Submitted by L. E. Locke, Sec'y.)

CHICAGO, January meeting. Dr. M. E. Merchant (former ASLE President), Assistant Director of Research for The Cincinnati Milling Machine Co., presented a paper entitled "Metal-Cutting Fluids & Radioactive Cutting Tools."

February. Ladies' Night; with W. F. Crummer, Illinois Bell Telephone Co., discussing "The Atom Bomb & I." (Submitted by J. N. Waddell, Sec'y-Treas.)

DAYTON, October '55 meeting. B. Dunham, Sun Oil Co., presented a paper entitled "Compressor Lubrication."

January. (Joint meeting with the American Society for Metals) "Free Machining Steels & Machinability from a Metallurgical Perspective," by G. H. Enzian, Jones & Laughlin Steel Co.

February. "Cutting Oils, Their Ingredients & Proper Application," by M. S. Oldham, The Texas Co.; and "Fire-Resistant Hydraulic Fluids," by H. Bradley, Socony Mobil Oil Co.

April. "Electric Motor Antifriction Bearing Lubrication," by E. L. Young, Delco Products Div., GMC. (Submitted by A. H. Lipton, Sec'y.)

FORT WAYNE, February meeting. M. A. Bigelow, assisted by

J. A. Burgess, both of the Chicago Division of Carbide & Carbon Chemical Co., presented a paper entitled "Fire-Resistant Hydraulic Fluids." (Submitted by J. W. Buckner, Chrmn.)

HOUSTON, January meeting. Election of Officers (see ASLE Directory). (Submitted by W. S. Nicholson, Sec'y.)

INDIANAPOLIS, October '55 meeting. A. O. DeHart, Research Engineer for General Motors Research, presented a paper entitled "Bearings, Materials—Designs & Lubrication."

November. Plant Tour of the Chrysler Corporation.

January. "Fire-Resistant Hydraulic Fluids," by J. B. Davis, Development Engineer of the Monsanto Chemical Co.

February. "Cutting Fluids & Their Application," by M. E. Merchant (former ASLE President), Assistant Director of Research for The Cincinnati Milling Machine Co.

March. "Preventive Maintenance by Means of Lubrication in Industrial Plants," by D. M. Cleaveland, Lubrication Engineer of Bendix Aviation Corp.

April 23. Plant Tour of the Bridgeport Brass Co.

May 28. "Fuels, Lubricants & Highlights of the 500 Mile Race," by R. G. McMahan, Socony Mobil Oil Co. (Submitted by C. M. Marlatt, Sec'y-Treas.)

LOS ANGELES, January meeting. L. D. Cobb, Manager of Research & Development for New Departure Div., GMC, presented a paper entitled "New Departure Ball Bearing Research Activities."

February. "Lubrication Problems of Gas & Air Compressors," by H. P. Henderson, Worthington Corp.

March. "Gear Lubrication in the Steel Industry," by J. P. Critchlow, Gulf Oil Corp.

April 10. "Oil Seals—History, Design & Application," by M. K. Gebert, Chief Research Engineer for National Motor Bearing Co.

May 8. "The How & Why of Ball Bearing Lubrication," by D. F. Wilcock, General Electric Co. (Submitted by R. F. Connelly, Publicity Chrmn.)

N. CALIFORNIA, January meeting. L. D. Cobb, Manager of Research & Development for New Departure Div., GMC, presented a paper dealing with the design, testing, and application of integrally sealed bearings, entitled "New Departure Ball Bearing Research Activities," highlighted by a film entitled "Accuracy to N^{D} Degree" concerning the manufacturing of bearings as produced by New Departure.

February. "Lubrication Problems of Gas & Air Compressors," by H. P. Henderson, Western District Engineer for Compressors & Engines, of the Worthington Corp. (Submitted by A. C. West, Sec'y.)

PITTSBURGH, January meeting. R. Guy, Lubrication Engineer for Detroit Transmission Div., GMC, presented a paper entitled "General Motors' Lubrication Standards." (Submitted by S. W. Settle, Publicity Chrmn.)

TWIN CITIES, January meeting. H. Ridder, National Petroleum News, presented a paper entitled "Automotive Gas Turbines." (Submitted by C. D. Johnson, Sec'y.)

WHEELING, February meeting. L. B. Sargent, Jr., Aluminum Co. of America, presented a paper entitled "Industrial Lubrication Laboratories."

March. A "Stump the Experts" session, with W. S. Fuhr (Pittsburgh Consolidated Coal Co.), J. P. Critchlow (Gulf Oil Corp.), and D. E. Whitehead (Crucible Steel Co. of America) as panelists. (Submitted by S. J. Litten, Sec'y-Treas.)

Personals

IN MEMORIUM. Neil I. Whiteley (an ASLE Sectional Sustaining Member since 1947, and former Chairman of the ASLE Cleveland Section), American Steel & Wire Co., Cleveland, Ohio, died December 4, 1955, following a brief illness.

W. Deutsch, ASLE President-Elect, has been appointed Manager of Industrial Sales of The Aro Equipment Corporation in Bryan, Ohio.

C. N. Norgren, Executive Vice-President of the C. A. Norgren Co., Englewood, Colo., has been elected 1st Vice-Chairman of the National Council of Profit Sharing Industries, and Vice-President of the Manufacturers Association of Colorado.

The Warren Refining & Chemical Co., Cleveland, Ohio, has announced the appointment of **J. J. Ferrie** as Sales Representative for its lubricating division in northern New Jersey, with headquarters in North Bergen.

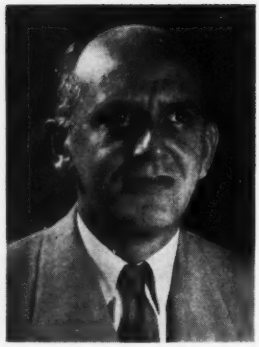
W. A. Brown, Jr., former President of The Liquid Carbonic Corp., has been appointed General Manager of the Alemite & Instrument Division of Stewart-Warner Corp., Chicago, Ill.

E. F. Houghton & Co., Philadelphia, Pa., has announced the appointments of **S. J. Barber** as Manager of the Metalworking Products Dept., and **C. G. Wall** as Supervisor of Metalworking Research.

J. H. Moran has been appointed Manager, Marine Sales Division, of The Texas Co., New York City.

Annual Meeting Authors

Pictured below and on the following four pages are the Authors and/or Co-Authors of the papers to be presented at the 11th Annual Meeting of the American Society of Lubrication Engineers, Hotel William Penn, Pittsburgh, April 4-5-6, 1956. Abstracts of papers to be presented, except for those arriving too late to meet publication deadlines, follow this section; they do not necessarily represent the final opinions of the authors and are subject to revision when the complete papers are published.



J. S. Aarons
U. S. Steel Corp.

A. W. Ackerman
F. E. Anderson Oil Co., Inc.

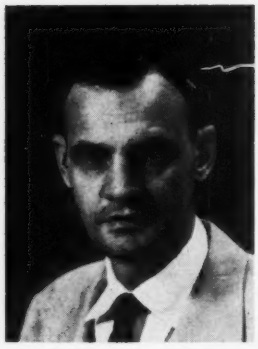
A. A. Anderson
General Mills, Inc.

F. E. Anderson
F. E. Anderson Oil Co., Inc.

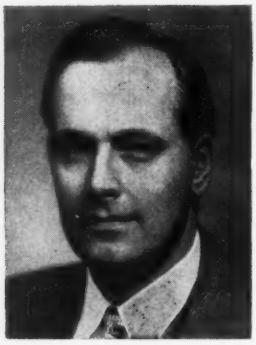
R. S. Barnes
Standard Oil Co. (Ind.)

R. S. Barnett
The Texas Co.

R. O. Bolt
California Research Corp.



R. C. Bowers
U. S. Naval Research Lab.



J. Boyd
Westinghouse Research Labs.

E. W. Brennan
The Pure Oil Co.

L. C. Brunstrum
Standard Oil Co. (Ind.)

D. B. Burroughs
J. A. Roebling's Sons Corp.

J. T. Burwell, Jr.
Horizons, Inc.

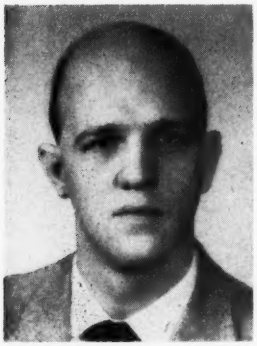
A. L. Busby
Armour Research Foundation

J. G. Carroll
California Research Corp.

A. E. Cichelli
Bethlehem Steel Co.

E. P. Cochran, Jr.
New York Naval Shipyard

L. F. Coffin, Jr.
General Electric Co.



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C. K. Fotopoulos
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C. E. Francis
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R. H. Leet
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H. L. Leland
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C. T. Lewis
Republic Steel Corp.

F. F. Ling
Carnegie Inst. of Technology

E. H. Loeser
Chrysler Corp.

M. F. Madarasz
Ford Motor Co.

J. E. Mayer, Jr.
U. S. Army

E. E. McClung
VanStraaten Chemical Co.

A. Miller
Armour Research Foundation

W. H. Millett
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R. G. Moyer
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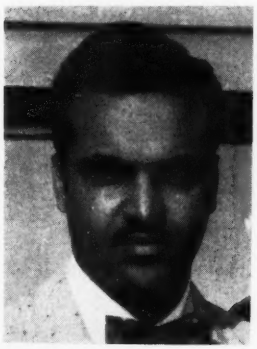

R. Samuel-Maharajah
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E. E. Shipley
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Rensselaer Polytechnic Inst.

B. Sternlicht
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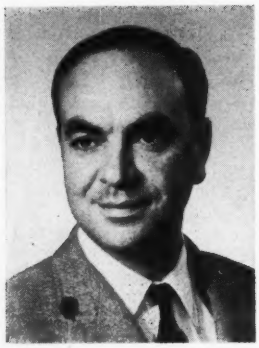
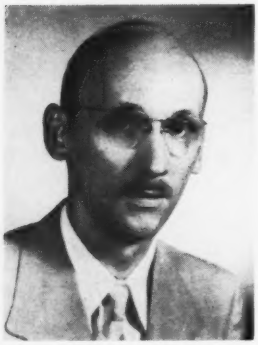
Socony Mobil Oil Co., Inc.



D. Tabor
Stanford Research Institute



D. M. Teague
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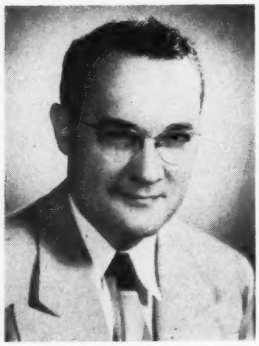
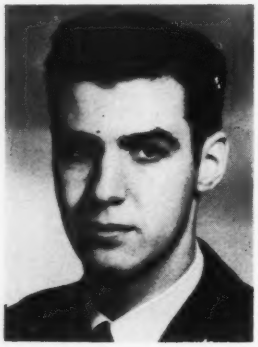
T. M. Thomas
U. S. Naval Research Lab.



S. B. Twiss
Chrysler Corp.

F. C. Wagner
Horizons, Inc.



J. H. Way
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Lewis Flight Propulsion Lab.

P. J. Willson
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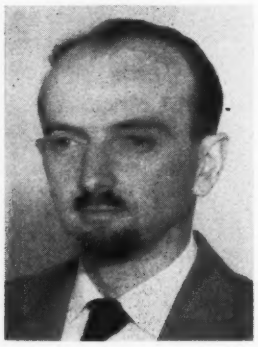

R. J. Wolfe
New York Naval Shipyard

W. A. Zisman
U. S. Naval Research Lab.

New ASLE Jewelry Available

Lapel pins and tie clasps featuring the new insignia, gold detail on a blue background with white lettering, are now available through the local Sections or National Office. The lapel pin is also being offered as a free premium to all members getting a new member. Details are available through the Sections or National Headquarters.

See the new jewelry at the annual meeting in Pittsburgh.

Lapel Pin $1.50
Tie Clasp $3.50

Annual Meeting Abstracts

The following abstracts of papers to be presented at the 1956 ASLE Annual Meeting, Hotel William Penn, Pittsburgh, April 4-5-6, are published herewith for general information and to stimulate discussion at the meeting.

Analysis Of Equilibrium Operating Temperatures Of Railroad Journal Bearings, by G. L. Pigman (Armour Research Foundation) & W. M. Keller (Assoc. of American Railroads). A graphical method of analysis is described for determining equilibrium operating temperatures of railroad journal bearings under various practical operating conditions. The method utilizes existing laboratory data describing friction characteristics of the railroad bearing, friction properties of the waste pack lubricator, and heat dissipation characteristics of the bearing assembly. These data are placed in convenient form and combined graphically to determine conditions of heat balance and the corresponding equilibrium oil film temperatures. Application of this method of analysis is found to provide convenient and valuable means for evaluating the effect of individual operating parameters upon railroad journal bearing performance. In particular, it is found that thermally unstable operating conditions exist where the bearing temperature tends to increase in an uncontrolled manner. In specific examples of use of this method, it is shown that particularly unfavorable combinations of operating conditions exist, within a range possibly encountered in railroad service, where thermally stable operation of the bearing cannot be obtained at high ambient air temperatures of about 100 F. Other examples show that increased bearing cooling, and reduction or elimination of waste pack friction, provide significant decrease in bearing operating temperature, and reduce the extent of the unstable operating regions. Reduction of oil viscosity, while also reducing the normal operating bearing temperature, increases the extent of the unstable region where bearing failure potentially can occur.

Appraisal Of Rolling Oil Testing, An, by S. A. Paradee (Archer-Daniels-Midland Co.). Work done in both this country and abroad is discussed with the end purpose being to clarify to some extent the thinking on this subject. Graphs and charts are shown to illustrate the types of testing already completed and new bench test methods. The reasons for need of development of laboratory technique is discussed at some length. Some of the variables in requirements of a suitable product are pointed out. While the paper does not deal with the rolling of ferrous or non-ferrous metals specifically, the variables encountered in cold rolling all metals are shown. One of the problems concerning protective annealing atmospheres is touched on, and actual gas analyses taken during an annealing cycle are shown. The paper is one which should prove of interest not only to the lubrication engineer but also to operating personnel.

Aqueous Fire-Resistant Hydraulic Fluids, by W. H. Millett (Carbide & Carbon Chemicals Co.). This paper is a review of the properties and performance characteristics of the aqueous-base, fire-resistant hydraulic fluids that are being widely used in industrial hydraulic equipment. It includes a brief historical summary of the development that led to the introduction of these products to industry, as well as a review of pertinent literature. Such properties as fire resistance, viscosity, corrosion protection, effect on seals and packings, wear resistance, solvent effects, and vapor pressure are discussed, and are related to overall hydraulic fluid properties. The importance of good maintenance practices is emphasized, and recommended procedures for installing aqueous fluids in hydraulic systems are outlined. The paper also discusses suitable methods for maintaining these fluids in service.

Assessment Of Automobile Bearing Performance From Field Tests, The, by W. E. Duckworth & P. G. Forrester (The Glacier Metal Co., Ltd., England). The conditions to which bearings are subjected in service include wide variations in load and temperature, presence of abrasive particles and complex cycles of starting, stopping, idling, and resting. These conditions are practically impossible to simulate in laboratory tests. The results of such tests cannot, therefore, be directly applied in practice, although they give valuable fundamental information. On the other hand, data from general service experience is difficult to obtain and frequently unreliable. This gap can be filled by controlled service tests, in which test bearings are fitted in standard vehicle engines operating under normal conditions. The test bearings and crankshaft are subjected to careful measurement for observing wear, and to close examination for qualitative assessment of results. By testing similar bearings in two different positions in the same engine, and by repeating test designs in different engines, the statistical significance of observed differences can be assessed and have reliable comparisons between materials obtained. Information on factors giving rise to high wear figures can also be obtained. Examples of test results are given.

Boundary Lubrication Studies Of Typical Fluoroesters, by R. C. Bowers, R. L. Cottington, T. M. Thomas & W. A. Zisman (U. S. Naval Research Lab.). The boundary lubricating and wear preventive properties of some new fluorinated diesters, which offer many advantages as high-temperature lubricants, have been investigated. These diesters were synthesized from aliphatic dibasic acids and nearly completely fluorinated alcohols. Friction and wear measurements were obtained using a "stick-slip" apparatus and a four-ball wear machine at temperatures from 77 to 400 F. The rubbing surfaces included hard steel, soft steel, and bronze. Fluoroesters containing typical anti-wear or oiliness additives were also studied. For comparative purposes results obtained with the familiar unfluorinated diester, bis(2-ethylhexyl) sebacate, are included. The frictional properties of the two classes of diesters did not differ sufficiently to be of practical significance. However, the fluoroesters had better wear preventive properties, especially at higher temperatures. Friction was markedly reduced by the addition of one percent stearic acid to either type of diester. The addition of two percent tricresyl phosphate was more effective in the fluoroester as an antiwear agent for hard steel on hard steel; approximately the same low wear rates were observed at 140, 266, and 400 F. The boundary lubricating ability of the fluoroesters, and their excellent response to conventional additives, invite their application as primary ingredients of stable high-temperature oils and greases.

Capillary Viscometry Of Lubricating Grease, by L. C. Brunstrum & R. H. Leet (Standard Oil Co. of Ind.). Detailed knowledge of the viscosity or flow resistance of grease is necessary in attacking practical and theoretical problems. Measurement of flow rates and pressures through capillaries is not difficult but, because of the complex nature of the flow, interpretation of results is. Interpretation may be made mathematically in four ways: The commonest is the ASTM method, which prescribes the apparatus but ignores several recognized inaccuracies; the observations are treated as though grease were a fluid, and lead to an "apparent viscosity". Another way, which may be applied to observations from many capillary viscometers, leads to viscosity at the capillary wall only; the results do not differ greatly from "apparent viscosity." A third way calculates values for yield value and mobility, on the premise that grease flows like a Bingham plastic; tables of dimensionless constants simplify the calculations. A fourth way takes a theoretical approach and determines an equation from flow data through Eyring's relaxation theory for viscous flow. The choice depends upon the problem. For specifications and empirical relations in lubrication problems, "apparent viscosity" and viscosity at the capillary wall may be used. Yield value and mobility could be used for calculating pressure drops in pipes as well as for specifications. Eyring's equation may permit correlating flow behavior with such

factors as size, shape, weight, distribution, and surface properties of thickener particles.

Chemical Machining & Grinding Fluids, by A. W. Ackerman & F. E. Anderson (F. E. Anderson Oil Co., Inc.). This paper presents a general theory of water-based cutting fluids and their function in metal working. A description and evaluation of the chemical, physical, and allied properties of the new chemical or synthetic cutting fluids is given. A revised and up-to-date Cutting Fluid Classification Table is included. The paper will discuss "solutions" and "emulsions," and will compare the chemical and conventional fluids on the basis of laboratory measurements of their cooling, anti-weld, and anti-wear characteristics. Changes in tooling or grinding wheels associated with the use of these fluids are described. Some industrial applications are discussed.

Concentration Effects Of Cutting Oil Additives In Performance Evaluation, by A. Dorinson (Sinclair Research Labs., Inc.). Performance tests, which included single-point lathe turning, orthogonal planing, and tapping, demonstrated the concentration-dependent activity of additives in cutting oils. From the parallelism of the relation between cutting speed and chip-tool interface temperature developed by Trigger and Chao, and the relation between cutting speed and tool life developed by Taylor, it was shown that the slope of the Taylor equation could be interpreted as the logarithmic temperature coefficient of tool life. With the aid of this interpretation, a hypothesis was constructed for the mechanism of cutting oil action, which involves the temperature-activated reaction of additive with metal. The observed phenomena of tool wear in the presence of a cutting oil will depend on the inter-relations, both in kind and quantity, between wear by metal to metal contact, and wear by chemical reaction with the additive. Tool life results obtained by turning tests, surface finish obtained by planer tests, and torque observed in tapping tests are discussed in the light of this hypothesis.

Crane Inspection, by T. E. Hughes (The Morgan Engineering Co.). A bottom view of electric overhead traveling cranes is about the only one that the vast majority of their users have ever seen. The maintenance men are the only people who really get to know this workhorse of industry. It is remarkable how far beyond original design expectations the overhead crane has performed, when it is considered how seldom major crane alterations have accompanied increased capacity of the equipment it services. There comes a time, however, when a comprehensive look at the crane condition cannot be avoided. In 1952 the author's company offered to industry the services of a survey team, equipped to properly inspect all types of cranes and to make recommendations based on their findings. It is hoped that the techniques of this team will be of interest to all who are planning a program of rehabilitation for E.O.T. cranes.

Current Research In The Bacteriology Of Soluble Oil Emulsions, by H. Pivnick, L. R. Sabina, R. Samuel-Maharajah & C. K. Fotopoulos (University of Nebraska). Pathogenic bacteria of the typhoid fever type grow in soluble oil emulsions containing indigenous pseudomonads. After several weeks in the emulsion, the pathogens are still virulent. Some soluble oils containing disinfectants allow as much growth of micro-organisms as oils without disinfectants. Several disinfectants recommended for addition to the emulsion are of no use in controlling bacterial growth. Soluble oil emulsions vary in their susceptibility to oxidation by a single species of bacteria, while different bacteria vary in their capacity to oxidize a single soluble oil. Some emulsifiers are more readily oxidized than others. Many common heterotrophic bacteria in oil emulsions are able to convert sulfur or thiosulfate to sulfide. Studies of the taxonomy and physiology by bacteria from soluble oil emulsions indicate that several previously unreported species are present. Some of these organisms possess unusual methods of metabolism.

Design & Testing Considerations Of Lubricants For Gear Applications, by E. E. Shipley (General Electric Co.). From a gear engineer's point of view, a good lubricant should have the following characteristics: (1) be readily available, (2) have low cost, (3) have good lubricity, (4) have low volatility, (5) have good thermal stability, (6) have good oxidation stability, (7) have good hydrolytic stability, and (8) have good viscosity—temperature characteristics. In general terms, the oil supply for any given gear design need not have all of the above characteristics, but the lubricant must perform the functions of satisfactorily lubricating the gear mesh to prevent wear and scoring, control the gear blank temperatures, and adequately serve as a lubricating medium for the bearings. In effect, the lubricant has become a constructural gear material. Gears fail in service, generally, from pitting of the gear teeth, breakage of the gear teeth, long range wear, and scoring. Wear and scoring are quite closely related to the lubricant, and the problem breaks down into three parts: (1) determining methods of evaluating the phenomena of wear and scoring on gear teeth, (2) determining methods of evaluating lubricants to find out their limits in terms of wear preventions and scoring prevention, and (3) determining methods of constructing new oils with the qualities needed to take full advantage of the lubricant as a constructional material. Laboratory personnel applied the radioactive technique of gear testing to the wear and scoring problems, as well as making theoretical investigation into the mechanisms of film lubrication. In addition, fundamental work was undertaken in the synthesis of new lubricants having outstanding wear and scoring resistance. Most of the company's work to date has been carried on with the following test equipment: Shell 4-Ball Wear Tester, Shell EP Tester, lubricated roll testing machine, Timken Wear Testing Machine, gear testing apparatus (4 square), and radioactive gear testing apparatus.

Discussion Of The Heat Treater's Problem In Quench Medium Selection, A, by C. R. Weir (Commonwealth Industries, Inc.). This paper shows how the factors of distortion, alloying materials, and hardenability must be considered by the heat treater in his selection of a proper quench medium. It also shows, for purposes of illustration, the use of isothermal transformation diagrams and cooling curves obtained from water, so-called normal quenching oils, and from fast quenching oils in such solutions. The paper concludes with an attempt to give the criteria for an ideal quench medium from the heat treater's point of view.

Disposal Of Soluble Oil Wastes, The, by E. E. McClung (VanStraaten Chemical Co.). The disposal of soluble oil wastes is covered by Federal, state, municipal, and other laws and regulations. As industry expands, the amount of industrial wastes will increase and the controls will become more rigid. Before disposal of wastes into state waters, and this includes soluble oil wastes, state laws require that permits must be obtained from the appropriate state regulatory body. The permits stipulate in parts per million, the maximum amount of oil allowable in the final water from split soluble oil waste, if such water enters state waters. The regulatory body issuing the permits usually has the authority to set these maximum amounts according to the volumes of soluble oil wastes and local conditions involved. A description of one method is given, which uses aluminum sulfate for splitting and calcium hydroxide for clarification of the final waste water. This method is being successfully used by some industrial plants for their soluble oil waste disposal and is meeting permit requirements. Results of laboratory runs on three different types of soluble oils are given, which field results confirm, and indicate what may be expected when this method is used.

Dynamic Demulsibility Characteristics Of Oils, by E. W. Brennan & R. G. Moyer (The Pure Oil Co.). The methods currently used to determine the demulsibility characteristics of circulating oils are quite empirical and afford little or no correlation with actual field performance. The Dynamic Demulsibility Apparatus constitutes a realistic approach, as it permits the evaluation of demulsibility characteristics essentially under field conditions. Data obtained by the con-

ventional methods and by Dynamic Demulsibility Test using a variety of lubricants are presented. The data indicate the test to be of value to both the research and the consumers.

Effect Of Engine Operation On Synthetic Gas Turbine Lubricants, by J. H. Way & T. F. Davidson (Wright Air Dev. Center). End application usage and its effect on lubricant performance is one of the most important environmental factors confronting the lubricant. In the case of aircraft gas turbines, the effect operation has on the lubricant's basic properties determines to an extent lubricant drain period and maintenance procedures and intervals. Data is given for six MIL-L-7808 type oils representing commonly used base stocks, showing the effect advance gas turbine operation had on these lubricant's properties. All Specification MIL-L-7808 properties, as well as specific heat and dielectric constant changes, are discussed as a function of operating time. Gas turbine operation creates some startling changes in the lubricant's basic properties, some being apparent improvements and others decidedly detrimental.

Electron Diffraction In Lubrication Research, by D. Godfrey (California Research Corp.). Electron diffraction is the most useful technique in revealing information on the nature of a surface. This paper reviews the contributions of electron diffraction in the field of lubrication research, and points out the important aspects of the technique as it is applied to this field. The theory of diffraction by crystals, specimen preparation, and pattern interpretation are covered. Examples of diffraction patterns from friction surfaces are presented.

Equilibrium Distribution Of Transfer Fragments, The, by E. Rabinowicz (Massachusetts Inst. of Tech.). During sliding, fragments are continually torn off one surface and transferred to the other. The final stages of this process are examined, and it is shown that two possible states of equilibrium exist, depending on the tightness of bonding of the transferred fragments. If the fragments are fairly loose, each surface normally retains its original configuration to a large extent; but if the fragments are tightly held, one surface often becomes completely covered by fragments of the other. A variety of experimental data is examined, and good agreement with the derived equations is found.

Evaluation Of Anti-Scuff Properties Of Oils, by D. M. Teague, E. H. Loeser, P. J. Willson & S. B. Twiss (Chrysler Corp.). A description is given of a bench-type lubricant tester for the study of metal scuff under combined sliding and rolling contact, with cyclic variation of load including the extreme-pressure range. The tester consists essentially of four spring-loaded tappets riding under complete lubrication conditions on rotating cams. The tester reproducibly differentiates between lubricating oils in accordance with their E.P. properties. The scuffing of a hardenable iron tappet riding on a cast iron cam is delayed by a run-in at moderate load, or by the use of an oil containing a small percentage of the additive, zinc dialkyl dithiophosphate. A run-in with a zinc dialkyl dithiophosphate oil protects the parts against scuff when a non-additive oil is used subsequently. The geometry of the mating parts has an effect on the incidence of scuff and is, therefore, held fairly constant. Oil viscosity, within the 10 W to SAE 30 range, has no effect on the incidence of scuff. Several processes may operate to prevent scuff. This study points up the mating of rubbing parts through controlled wear as an important mechanism in scuff prevention.

Evaluation Of Anti-Wear Properties Of Oils, by S. B. Twiss, E. H. Loeser & D. M. Teague (Chrysler Corp.). A lubricant tester, designed for the study of metal scuff under combined sliding and rolling contact with cyclic variation of load, can be used to evaluate wear before scuffing occurs. The applied spring-loading of this cam and tappet-type tester is increased in equal increments. The changes in the surface contour and roughness of the mating parts is followed by making proficorder and profilometer traces at various intervals during the run. The wear of the cam and tappet test pieces is calculated from the proficorder traces; the loss in weight of the tappet is determined also. In general, the wear appears to be rapid during the early part of a run and moderates as the run progresses, in spite of the fact that the applied load is being increased. The addition of 0.75 percent of a chemically active additive, zinc dialkyl dithiophosphate, to the oil increases the wear of the cast iron cam several fold, but appears to have less effect on the hardenable iron tappet wear. The wear of the cam varies directly with the amount of this additive in the oil. This increased wear, however, is too small to adversely affect the operation of an automotive valve train.

Experimental Investigation Of Railroad Journal Bearing Operating Characteristics, by G. L. Pigman & A. L. Busby (Armour Research Foundation). Measurements were made of the coefficient of journal friction and oil flow through the bearing for successive stages of seating of 6-in. by 11-in. babbitt railroad journal bearings. Such data were obtained with the initial bearing radial clearance varying from 0.003-in. to 0.250-in. representing a range encountered in railroad practice. It is shown that the performance characteristics of the babbitt bearing do not change significantly with further wear after a seating width of about 2-in. is established. The time required to obtain this minimum seating width is increased with use of large initial clearance. A minimum coefficient of journal friction of about 0.003 is obtained at a ZN/p value of 4 with a full seated bearing. Friction and oil flow data are compared with values computed from theory, as based both upon assumed existence of negative pressures in the bearing oil film and upon assumed occurrence of cavitation in the oil film. It is shown that measured data agree reasonably closely with computed values based upon oil film cavitation, whereas the theoretical friction curve based upon negative oil film pressures shows considerable deviation for conditions of large bearing loading. It is indicated from the measured and computed data that minimum friction occurs at a minimum oil film thickness of about 0.0002 in.

Grease Flow In Shielded Bearings, by R. O'Halloran, J. J. Kolfenbach & H. L. Leland (Esso Research & Engrg. Co.). Grease as an entity flows quite freely between the bearing proper and the shielded bearing service. This transfer of grease between shields and bearing occurs even with highly channeled greases. This study suggests that proposed mechanisms for grease lubrication, which state that lubrication is affected only by oil bleeding from the soap-sponge, are not covered for the 204-type bearings examined. Techniques and results are given.

Grinding Temperatures, by J. E. Mayer, Jr. (U. S. Army) & M. C. Shaw (Massachusetts Inst. of Tech.). The several types of temperatures that are of interest in grinding operations are discussed, and it is concluded that the temperature at the very surface is the one of major interest with regard to crack formation and surface damage. Apparatus is described for measuring the temperature of a freshly ground surface by means of a photoconducting lead sulfide cell and an oscilloscope. The experimentally-observed surface temperatures were found to vary in the same way with chip size as calculated temperatures based on specific grinding energy. Both water- and oil-base fluids were found to significantly reduce surface temperatures over dry grinding. Oil-base materials were found to give slightly lower temperatures than water-base materials due to the superior lubrication action of the oils more than offsetting their relatively poorer cooling action.

High-Temperature Lubricant Studies, by E. E. Klaus & M. R. Fenske (The Pennsylvania State Univ.). The need to operate some hydraulic fluids and lubricants at increasing temperatures (above 400 F.) emphasizes the need for basic studies in the 500-700 F. range. First it was necessary to develop reliable test procedures and techniques covering the measurement of viscosity, lubricity, corrosion, and oxidation and thermal stability at temperatures of 500-700 F.

Several fluids were evaluated in this manner. These fluids are representative of the different chemical classes, such as silicones, silicates, hydrocarbons and mineral oils, diesters, and halogenated aromatic hydrocarbons. It was found that the property differences between the various types of fluids at 500-700 F. were much narrower than exist in the 200-350 F. range. Data are presented showing the inadequacy of extrapolating 200-350 F. data as a means of predicting performance at 500-700 F. The behavior of fluids and lubricants in the 200-350 F. range has been quite well defined in recent years for the materials used in this study. However, there is a paucity of information at 500-700 F. This paper attempts to remedy somewhat this situation.

Investigation Of Oil Additives For Boundary Lubrication Of Railroad Journal Bearings, by A. Miller (Armour Research Foundation) & A. A. Anderson (General Mills, Inc.). The boundary friction properties of the lubricated system of steel sliding on lead-base babbitt were investigated as a phase of the Association of American Railroads' sponsored project on freight car hot boxes. A friction pendulum was developed for determining the coefficients of boundary friction as a function of temperature with the specified metals lubricated with various lube oil additive blends. A group of general relationships dealing with additives for the steel-babbitt system was developed. It is concluded that the extreme pressure agents containing sulfur or chlorine are generally unsuited for railroad journal bearing use. Lubricity additives which function by simple physical adsorption were found to be ineffective at moderate or high temperatures existing in railroad operations. Those lubricity additives which chemisorb to metal surfaces and form a close-packed layer were found to be effective anti-friction agents.

Lubrication Engineer Surveys Steel Mill Gearing, A, by A. E. Cichelli (Bethlehem Steel Co.). Long, uninterrupted gear life for such periods as ten or even twenty years is the dream of every maintenance engineer in the steel industry. Such longevity has been experienced, but in this era of higher speeds and loads, similar good records are less likely to be attained. This paper reviews numerous examples of gear units in service in steel mills, analyzing their performance in the light of facts as they were found. The author points out that many cases of gear failure attributed to poor lubrication were actually due to design factors.

Lubrication In The Presence Of Nuclear Radiation, by R. O. Bolt & J. G. Carroll (California Research Corp.). Some effects of pile radiation on the lubrication of bearings and gears have been investigated. Three special lubricants, shown from previous studies to have unusual radiation stability, were used. Apparatus of two types was operated at 285 F. in a nuclear pile. Motor-driven journal bearings were run at 80 rpm through a gear train. Air turbines supported by ring-oiled ball bearings were operated at about 10,000 rpm. Each test was duplicated in the absence of radiation. Radiation damage markedly shortened the useful life of the lubricants.

Mechanism Of "Free" Rolling Friction, by D. Tabor (Cambridge Univ., & Stanford Research Inst.). This paper deals with the origin of the resistance to motion observed when a sphere or cylinder rolls freely over a solid surface. With metals the rolling in the initial stages usually involves plastic deformation, and the major part of the rolling friction is due to the plastic displacement of material ahead of the rolling element. With repeated traversals of the surface, an equilibrium state is reached in which plastic flow comes to an end, and the deformation is essentially elastic. Rolling friction in the elastic range is of considerable importance, since it is probable that ball or roller bearings, in practice, operate under these conditions. Earlier workers attributed rolling friction to microslip at the rolling interface. The present study shows that such microslip, in general, contributes only a trivial part to the observed rolling resistance. It is suggested that the major part arises from elastic hysteresis losses within the metals themselves. This would explain the observation that the rolling resistance is scarcely affected by the presence of boundary lubricants. However, lubrication can produce an appreciable diminution in the amount of metallic transfer and wear. It is concluded that under conditions of free rolling there is little "conventional" friction. The new point brought out is the large part played by hysteresis losses in the rolling resistance.

New Retainer Materials For Aircraft Gas Turbine Bearings, by F. C. Wagner & J. T. Burwell, Jr. (Horizons, Inc.). A study of the wear behavior of several classes of potential cage materials for aircraft gas turbine bearings was conducted, using a special wear testing machine to simulate roughly the projected service conditions of such bearings. The tests were made at temperatures up to 800 F., at a surface rubbing speed of about 400 feet per second, and were lubricated by oil jets directed against the rubbing interface. The materials were tested in rubbing contact with a toolsteel disk, and were evaluated on the basis of (1) their wear rates as a function of temperature, (2) the tendency to cause vibration in the machine, and (3) the extent to which metal transfer to and scoring of the toolsteel disk occurred. It was found that: (a) Several heterogenous alloys containing silver as a soft, low shear strength phase showed superior wear properties to "S" Monel and iron-silicon bronze, even when silver-plated. The latter alloys were used as reference cage materials. (b) The hard, load-supporting phase showing the most promise was a nickel base with additives of borides, silicides, or carbides. (c) The materials showing the best wear properties were most efficiently fabricated by powder metallurgy techniques, utilizing the infiltration method for adding the silver.

Numerical Solution Of Reynolds' Equation For Sector Thrust Bearings, by B. Sternlicht (General Electric Co.) & H. J. Sneck, Jr. (Rensselaer Polytechnic Inst.). Computer technique was employed for the solution of Reynolds' equation in cylindrical coordinates. The equations were set up in dimensionless form and then transformed into difference equations. By process of iteration, using the IBM 650 Digital Computer, solutions of load-carrying capacity and flow of thrust bearings were obtained. The variables considered were film shape, viscosity, and velocity. Whenever possible, solutions were checked against existing mathematical solutions. A comparison between Michell's exact solution, Saibel's exponential solution, and iterative solution is included in table and figure.

On A Criterion Of Cutting Velocity In Metal Machining, by E. Saibel & F. F. Ling (Carnegie Inst. of Technology). The conventional model of orthogonal cutting with type 2 chip is modified to include the effect of deformation of the work-piece at the immediate vicinity of the tool-tip. The cutting velocity conditions for optimal force of deformation is examined in the light of two alternate criteria: recrystallization temperature and melting temperature. It is shown that a critical cutting velocity exists. Furthermore, it is concluded, in part, that proper metallurgical treatment and/or preheating the work piece (hot machining) will improve cutting.

Problems In Hydrodynamic Lubrication, by E. K. Gatcombe (U. S. Naval Postgraduate School). This paper presents a short discussion and analysis of three common lubrication problems, namely: (1) gear tooth lubrication, (2) thrust bearing lubrication, and (3) sleeve bearing lubrication. The hydrodynamic theory itself is discussed. The assumptions and limitations of the theory are discussed as the theory is applied to the analysis of these problems. The analyses show that reasonable film thicknesses, film pressures, etc., exist in each of these applications, as has been demonstrated in actual tests.

Solution For The Finite Journal Bearings And Its Application To Analysis & Design, A, by A. A. Raimondi & J. Boyd (Westinghouse Research Labs.). An extension of the authors' previous work on the analysis and design of journal bearings. Numerical solutions have been obtained for finite journal bearings of various arcs and having length-to-diame-

ter ratio equal to one. Data have been put in chart and table form enabling rapid calculation of performance characteristics. Typical bearing design examples are included which illustrate the facility with which theoretical calculations can be made.

Spray & Drip Methods Of Applying Lubricant To Wire Rope, The, by D. B. Burroughs (J. A. Roebling's Sons Corp.). In recent years more and more wire rope users in many fields have become aware of the increased safety and operating benefits gained by lubricating wire rope in service. The development of new and improved lubricants has enabled users to get effective rope lubrication by the relatively easy spray and drip methods of application. At the present time a number of major wire rope installations use either of these methods for semi-automatic or completely automatic lubrication of wire rope. Mine hoists, elevators, tramways, and earth moving equipment are just a few such installations. Lubricants with widely varying characteristics have done much to make the spray and drip methods adaptable for use on most types of equipment. Additives that give lubricant special properties have proven of great value in facilitating application as well as improving rope service.

Study Of Combustion-Resistant Hydraulic Fluids As Ball Bearing Lubricants, A, by H. V. Cordiano, E. P. Cochran, Jr., & R. J. Wolfe (New York Naval Shipyard). When used as flood lubricants, phosphate ester, phosphate ester-base, and water-glycol base combustion-resistant hydraulic fluids significantly reduce the life of angular contact ball bearings below that obtained with petroleum oil. Under a lighter bearing load, the fluids retain the same order of merit as that found for a heavy load. At moderately higher fluid temperatures, bearing life is further reduced. The pressure viscosity relations of the fluids at different temperatures have also been determined for possible correlation with the results of bearing tests. Other related studies have also been made for the purpose of seeking the cause for the reduction in life of bearings lubricated with combustion-resistant hydraulic fluids.

Surface Film Thickness & Boundary Lubrication, by I-Ming Feng (Bendix Aviation Corp.). The thickness of a surface film when it just exceeds the average depth of plastic roughening is of critical importance. If the load is kept constant, the average depth of plastic roughening does not change. When the thickness of the surface film approaches and finally becomes greater than the critical valve, the weakening of the interlocking effect of the plastic roughening causes rapid decrease in wear, and ultimately reduces wear to practically zero. The average depth of roughening increases with load. If the film thickness is kept constant, rapid rise of wear will occur when the critical film thickness is exceeded due to increased load. This paper will also include experimental data directly verifying these conclusions.

Surface Viscosity & Elasticity Of Lubricating Oils, by D. W. Criddle (California Research Corp.). Some additives alter the surface viscosity and elasticity of a film of lubricating oil. These surface properties are readily measured at oil-air and oil-water interfaces with a torsion pendulum surface viscometer. Viscosity and elasticity data at oil-air and oil-water interfaces are summarized. New data are presented for sorbitan sesquioleate at several oil-water interfaces. A discussion is given of the significance of surface viscosity and elasticity in foaming, in emulsion stability, and in boundary lubrication.

Synthetic Ester Lubricants With Improved Lubricity & Thermal Stability, by M. Z. Fainman & R. S. Barnes (Standard Oil Co. of Ind.). Synthetic esters have properties that make them good lubricants under conditions too severe for mineral oils. Raw materials for synthesis are available on a large scale from petroleum sources. Early research in Germany led to commercial production mostly from polyhydric alcohols and monobasic acids. Development in Britain and the U.S.A. concentrated on esters derived from monohydric alcohols and di-basic acids. Lubricants with particularly good properties can be made from polyhydric alcohols and monobasic acids. Polyols derived from neopentane have no hydrogen atoms on the betacarbon atom, and give esters of improved thermal stability. Straight-chain monobasic acids give good lubricity. Such esters improve the lubricity of silicone oils as well as mineral oils.

Tapping Test For Evaluating Cutting Fluids, The, by C. D. Flemming & L. H. Sudholz (Socony Mobil Oil Co., Inc.). A tapping test is described wherein torque measurements, when compared with a standard, are used as a means of evaluating cutting fluids. Typical test results, and trends in metal cutting efficiency based on the characteristics of the fluids, are shown. Discussion is given to indicate the correlation with field service data in the more severe machining operations. Interpretation of test results are somewhat limited with respect to types of metals and machining operations. However, this test provides a rapid, economical, and sufficiently accurate means of evaluating cutting fluids for most uses.

Transition Temperature For Surface Damage In Sliding Metallic Contact, A, by L. F. Coffin, Jr. (General Electric Co.). In an earlier paper it was observed that in inert atmospheres two distinct kinds of repetitive sliding occurred for metallic couples. These were categorized: (a) sliding by shear, and (b) sliding by welding. Mode (a) was observed to occur for non-alloying couples, and was typified by relatively low coefficient of friction, a smooth and relatively small contact area on the slider, and a narrow and smooth wear track on the mating disk; whereas mode (b) occurred for alloying couples, and was identified by high coefficient of friction, a large and abraded contact area on the slider, and similar damage to the wear track. The present paper considers the effect of liquid atmosphere and temperature on the repetitive sliding alloying couples, particularly copper-copper, copper-nickel and nickel-nickel. A transition temperature is observed for the various liquids tested, below which sliding by shear, mode (a), is observed, and above which mode (b) form of sliding takes place. The transition is very sharp with temperature, and is found to be repetitive as the temperature is raised or lowered through the critical range. Thus the "damage" introduced, by sliding for prolonged periods above the critical temperature, can be "repaired" by continuing the sliding at temperatures below the critical by value. The significance of such variables as speed of sliding, normal load, kind of fluid, and kind of metal on the critical temperature are investigated, and a mechanism for the phenomenon is proposed based on surface diffusion effects.

Treatment Of Oil Wastes From Machining Plants, by M. F. Madarasz (Ford Motor Co.). A large increase in oil consumption has resulted from industrial expansion. Prior to treatment of oil waste, installation of individual oil pans around machines can substantially reduce oil losses. Other conservation measures, such as "good housekeeping" and a continued preventive maintenance program, can result in (1) lower oil consumption, (2) quantities of oil waste requiring treatment, and (3) reduction in waste treatment facility size. Filtration and sedimentation can successfully be applied to cutting, honing, and emulsified oils. Efficiency of filtration and sedimentation can be affected by substituting oils. Data showing efficiency of various filtration and sedimentation are tabulated. Sources of oil wastes are washers, cutting, grinding, and lubricating operations. Sizing of a waste treatment plant can be determined by water consumption for washers, emulsified oil requirements, and inventory records. Described is a waste treatment plant treating 1,000 gallons per minute of continuous oil waste water with variations of 200 to 40,000 parts per million of oil. Effluent of the waste treatment plant does not exceed 10 parts per million of oil and 10 parts per million of suspended solids. Similar treatment plants are being constructed for new Ford Motor Company operations where machining is done.

Use Of An Automatic Viscometer For The Study Of Lubricant Flow, The, by R. N. Weltmann & P. W. Kuhns (NACA, Lewis Flight Prop. Lab.). This paper will attempt to analyze the flow behavior of some lubricants, from programmed flow curves of rate of shear versus shearing stress, and from curves of shearing stress versus time. These curves were obtained over an extended range of shear, under fully controlled shear and time conditions, and at various constant temperatures. The necessity of having such curves for a meaningful analysis of the flow behavior of lubricants, which are shear- and time-dependent, will be discussed. The automatic rotational viscometer that is used to obtain these curves will be described. This viscometer has provisions for continuously varying the speed at a constant rate, for automatically recording the instantaneous values of torque and speed, and for programming the flow curves to be taken. The range of the instrument permits shearing stresses from 50 to 250,000 dynes/cm^2, rates of shear from 0 to 4000 sec^{-1}, and viscosity measurements from .05 to about 60 poises for 4000 sec^{-1}.

Where We Stand On Fire-Resistant Turbine Fluids: A Progress Report, by J. J. O'Connor (McGraw-Hill Publishing Co.). For many years power men have been making sporadic attempts at finding a turbine lubricant that was really fire-resistant. In the spring of last year, interest in the subject was revived when chemical manufacturers and one oil supplier agreed that materials on hand showed distinct promise. Field tests were run on turbine-driven boiler feed pumps; results to date look good with a few reservations. There is much concern about the possible harmful effect of such materials on generator windings. Feasibility of protecting existing generator windings against the fire-resistant fluids is being studied. The author will present a timely progress report on who in the country is working with fire-resistant turbine fluids at present, what materials show promise, what problems must still be licked, the economic advantage to the power industry when suitable F-R fluids are adopted.

New Products

Aviation Maintenance Equipment. Pre-control of a desired volume automatically is possible using meters now being supplied for equipment designed for servicing aircraft. Shown are two of the units manufactured by Garsite Products, Inc., Seaford, N. Y., utilizing meters manufactured by the Granberg Corp. of Oakland, Calif., under the trade name "Granco." The first unit is a 150 gpm Airport Hydrant Refueling Cart with a hydraulic shock eliminator. The second unit is an aviation pneumatic lube oil dispenser containing an 80-gallon capacity tank. Delivery at the nozzle is 11 gallons per minute.

New Morehouse Mill Line. A new improved line of Morehouse Mills for the process industries has been announced by Morehouse-Cowles, Inc., national distributors for Morehouse Mills and Cowles Dissolvers. All models of the advanced Morehouse line feature new handwheel adjustment with micrometer setting and positive lock, magnetic swirl arrester that reduces splash and removes tramp metal, built-in stop that indicates time for stone replacement, new easier time-saving method for head and stone removal and replacement, and an external grease fitting. (Morehouse-Cowles, Inc., LE-12/2, 1150 San Fernando Road, Los Angeles 65, Calif.)

Hydraulic Accumulator. By accurately storing up energy during selected time of cycle, large expensive electric motors and electrical controls are eliminated and replaced by small, economically operated motors. The John S. Barnes Corp. has designed and patented an Accumulator featuring a unique diaphragm which is only flexed, never stretched, and operates indefinitely without loss of pre-charge pressure supplied by either nitrogen or regular air under pressure. Typical of its many uses are traversing mechanisms, indexing turrets for high-speed lathes, clamping and actuating devices of all types. (J. S. Barnes Corp., LE-12/2, Rockford, Ill.)

All-Purpose Absorbent. An industrial floor absorbent said to soak up more than its own weight in oil, greases, and other fluids, has been recently developed under the trade name "Pickup." Unaffected by heat or cold, this absorbent's low density per cubic foot provides absorption of oil, greases, water, and acids; being chemically neutral, it will not injure personnel or equipment. Manufacturer reports the absorbent to have been approved by Underwriter's Laboratory and to be safe for use on industrial floor surfaces. (The Diversey Corp., LE-12/2, 1820 Roscoe St., Chicago 13, Ill.)

Disposable Wipers. A new and smaller size wiper for industrial use has been introduced by the Scott Paper Co. Designated "No. 58," the new wiper is a two-ply sheet measuring 9⅝ x 10¼ inches. According to the manufacturer, advantages from the new product will permit solution to problems of high unit cost, expensive handling, erratic performance, shrinkage, pilferage, and laundry losses from other methods. (Scott Paper Co., LE-12/2, Chester, Pa.)

Template Kit. A new matched set of five reversible templates for drawing general layouts or details of any valving and piping system has been devised which contains all American Standard

symbols, has provisions for new or special symbols, and is claimed to be the most complete diagramming outfit devised for such work. At least 5000 commonly used pipe, fitting, and valve diagrams can be pencil drawn with great accuracy by using the cut out symbols on the templates singly or in combinations. Layouts can be made for any fluid or gaseous processes such as pipelining, refining, pumping, pneumatic, hydraulic, plumbing, heating, refrigeration, steam, high pressure, drainage, sprinkler, and vacuum. All are made of rigid, non-glare vinyl. (A. Lawrence Karp, LE-12/2, 16 Putnam Park, Greenwich, Conn.)

Bonding Cement. A new solvent cement for joining polyvinyl chloride (PVC) pipe fittings and flanges has been announced that makes possible a joint as strong or stronger than the pipe, and is capable of bridging a greater diametral gap than any previously available bonding agent. The new cement permits solvent welding of any SPI approved piping of PVC. (Tube Turns Plastics, Inc., LE-12/2, Louisville 11, Ky.)

Nylon Pressure Tubing. A new, specially processed, flexible nylon tubing, trademarked "Nylaflow," will be shown by The Polymer Corp. of Pennsylvania at the 1956 ASLE Annual Meeting & Exhibit. Nylaflow tubing has been used successfully as a conveyor for air, gas, and liquids. Lincoln Engineering Co. first introduced it to the lubrication field with their Multi-Luber push button lubrication system for automobiles. It has since been engineered for hydraulic, air, vacuum, fuel, and oil lines. Labeled a "pressure" tubing because of its outstanding burst rating per unit weight, it exhibits high resistance to flex and vibrational fatigue, abrasion and impact resistance, and lightness and convenience in handling. New technical information will be available to assist engineers in applying this new tubing to their requirements. Active demonstrations will be presented. (The Polymer Corp. of Pa., 125 N. 4th St., Reading, Pa.)

Synthetic Lubricant. A product that dissolves instantly in any kind of water to make a clear, thin, odorless lubricant that has good wetting properties, exceptional heat absorbing and convection properties, and that gives positive protection against rust has recently been developed by the Harry Miller Corp. The product, called "Hami-Kleer No. 1391," helps increase tool life because of exceptional lubricity and anti-weld properties, and it facilitates all metal-working operations on all ferrous metals including cast iron and cast steel. The lubricant cannot decompose, turn rancid during use, or affect workers' skin. In addition, it will not gum, become tacky or foam, and can be run down drains without special treatment if oils do not get into the mixture. Since there are no oils present in the lubricant, grinders and reservoirs remain clean and sweet-smelling at all times, and it is said that fine surface finish is assured because tool and work are constantly kept cool and clean. For grinding steel, stainless, alloys, etc., the dilution is 1:40 up to 1:70. For other metal-working operations the average dilution is 1:30 with water. For cutting, grinding, and hydrostatic testing cast iron, steel, or cast steel, the average dilution is 1:20 up to 1:70. (Harry Miller Corp., LE-12/2, 4th & Bristol Sts., Phila., 40, Pa.)

Lubrication in the News

SALUTE TO E. G. ACHESON. In tribute to the memory of Dr. Edward Goodrich Acheson, the 100th anniversary birthday of the founder of Acheson Colloids Co., Port Huron, Mich., was celebrated by the closing of the Company's plants and offices on March 9. The importance of this date to the entire world is indicated by two simple references: Webster's New International Dictionary reads "Acheson, Edward Goodrich. American Inventor. (Carborundum.) 1856-1931;" and the other, made on Acheson's death by another American inventor, Thomas A. Edison, "As a former associate I know the world loses a great genius."

Acheson's first great invention was silicon carbide which he called "Carborundum," a hard abrasive material that worked so well in metal-shaping that it was one of the major contributing factors in the growth of mass production, responsible for America's industrial and agricultural revolution.

Later, Acheson's genius made an equally great contribution with the discovery of a process to manufacture graphite. This material, one of Nature's softest solids, was made by Acheson with extremely high temperatures by a process similar to that which gave him silicon carbide.

From his experiments with graphite, came Acheson's discovery of a method to render it colloidal. Colloidal graphite dispersed in water was first prepared in 1906. Shortly afterwards, a colloidal graphite dispersion in petroleum oil appeared. Together they opened a new era in industrial lubrication, and secured Dr. Acheson's role as one of the pioneers of our modern industrial world.

Improved Chemical & Petroleum Research to Result from New Distillation Method. A new technique which reportedly surpasses present-day distillation efficiencies, has been announced by the Gulf Oil Laboratories. Called gas-liquid partition chromatography, the technique is based on a phenomenon of physical chemistry only recently introduced to practical use by English scientists.

Gas-liquid partition chromatography quickly separates gases and liquids whose boiling points are so close that present-day distilling columns either cannot take them apart, or require weeks for the separation. Only trace amounts are required for analysis, thus conserving costly research materials and permitting analysis of quantities too small for distillation methods. The ap-

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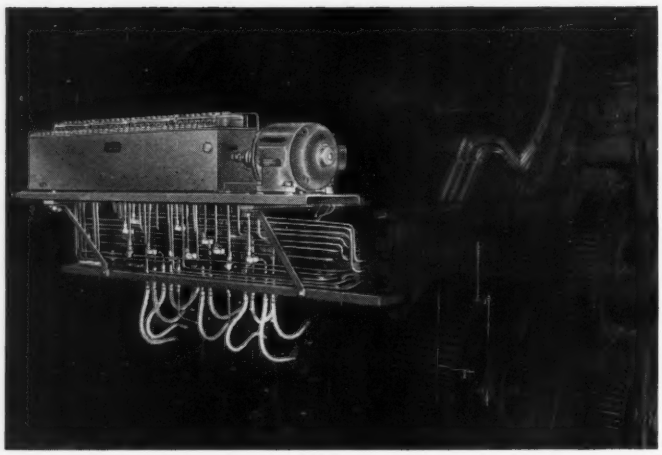

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paratus employed can be described as a long thin tube filled with a granular powder which is coated with an oily substance. The tube is maintained at constant temperatures up to 300 F. Samples to be studied are injected with a hypodermic needle into the chromatographic tube. Part of the fluid being studied goes into solution with the oily matter on the grains, and the rest becomes a gas in the spaces between the grains. By introducing a "carrier gas" into the tube, the gas in the spaces is forced ahead; additional matter comes out of solution into the voids between the grains, and is in turn moved forward by the "carrier gas." The process is continuous so long as the supply of "carrier gas" is maintained. Different components of the material under study move down into the tube at different rates because each displays a different equilibrium between its soluble phase in the oily material and its gaseous phase in the spaces between grains. As each component emerges from the end of the tube, it is detected by a conventional thermal conductivity cell and identified on the basis of its transit time through the tube. Under the conditions described, the various compounds in a mixture can be made to move forward in a tube at different speeds and thereby easily separated at the end.

Fisher Scientific Co., Pittsburgh, Pa., will produce a commercial Gas-Liquid Partition Chromatography unit. Data on the new instrument can be obtained through Fisher.

Centralized Lubrication. A centralized lubrication system for cars, trucks, buses, tractors, or any vehicle or equipment having an internal combustion engine, and which automatically delivers a controlled, measured amount of lubricant to as many as thirty lubrication points or bearings each time the engine is started, has been announced by the Alemite Division of the Stewart-Warner Corp., Chicago, Ill.

The system consists of a vacuum-operated pump from which tubing carries lubricant to a posi-

tive displacement measuring valve located at every bearing. A single-line terminating system, it is energized whenever the ignition of the car is turned on and the engine is started. An indicating light on the instrument panel glows while the system cycles; if it fails to light, it indicates to the driver that there is a fault in the system — a broken line or lack of lubricant in the reservoir.

In installing the system, measuring valves are substituted for fittings at all lubrication points requiring a ⅛" P.T. fitting. Where drive or rivet-type hydraulic fittings are used, a measuring valve with a compression-type nut and sleeve is fastened to the hydraulic fitting.

Lubricant lines are of nylon tubing having a 2,500 psi burst; a varnished fibre glass sleeving protects the nylon tubing from abrasion. The vacuum pump which supplies lubricant to the lines provides 500 psi pressure at the end of the line. Positive displacement measuring valves at every bearing deliver .003 cubic inches of either oil or Type 0 grease. The output of the pump, on each stroke, is sufficient to serve 30 valves on a single system. The single-line terminating system is factory-filled with lubricant to eliminate air pockets. The lubricant reservoir of the pump has an indicator to show the level of lubricant, which is supplied in 8 oz. cans.

Under normal operating conditions, the only attention the Alemite system requires is replenishment of lubricant supply, as indicated at the pump or by failure of the light on the instrument panel to glow when the engine is started.

Lubrication Abstracts

(This is the fourth in a series of abstracts of translations of Foreign articles on lubrication, by Henry Brutcher. Copies of the full translations are available, at the indicated prices, by writing Mr. Brutcher at P.O. Box 157, Altadena, Calif.)

Influence of Different Conditions of Drawing upon Die Pull Ratio & Mechanical Properties of Steel Wire, by F. Schwier; "Stahl und Eisen," Vol. 61, 1941; 14 figs., 2 tables, 10,100 words. Report on extensive experiments on wire drawing conducted entirely under conditions of practice. Steels studied: .06% C, .40% C, and .60% C steels. Experimental procedure and results. Influence of lubricant and other factors on ratio of theoretical or actual die pull and mechanical properties of wire, taking into consideration different drawing speeds. Lubricants studied: powdered soap, drawing grease compounded of tallow and castor oil, rapeseed oil, straight castor oil, machine oil, straight tallow, and straight wax. (Order No. 1111, Price $12.60)

Commercial Production of New Chrome-Aluminum Steels with the Use of Master Alloys, by I. Kornilov & V. Mikheyev; (Kharkov) "Stal," Vol. 10, 1940; 4 figs., 4 tables, 4,900 words. Commercial production of Cr-Al steels of special purity by use of Cr-Al master alloys and a CaO-MgO-Al_2O_3 slag. Commercial production of a series of Cr-Al steels; trial melts in a 110-lb. basic h.f. furnace. Composition of steels melted . . . cold drawing properties; best lubricant. (Order No. 1254, Price $6.10)

Influence of Lubricant on Power Requirements in the Drawing of Carbon Steel Wire with Tungsten Carbide Dies, by A. Pomp & A. Koch; "Mitteilungen," K. W. Institut Eisenforschung, Vol. 13, No. 22, 1931; 7 figs., 1,400-word abstract. Investigation of effect of various lubricants on power requirements in the drawing of 0.06 and 0.53% C steel wire under conditions of practice. Experimental setup and procedure. Lubricants tested: powdered soap, rapeseed oil, mineral wire-drawing oil (M20), soda grease, and lime grease. Deformation efficiency (ratio of theoretical to actual die pull × 100%) as function of entrance angle of die hole, with the different lubricants. Evaluation of performance of the lubricants tested. Causes of scoring of wire. Effect of drawing speed on power requirements and occurrence of scoring. (Order No. 1663, Price $2.10)

Strain Hardening of Aluminum During Cutting in Inactive and in Surface-Active Cutting Fluids, by N. A. Pleteneva, L. A. Shreiner & P. A. Rebinder; "Doklady Akademii Nauk SSSR," Vol. 62, No. 5, 1948, pp. 653-655; 2 figs., 1 table, 1,000 words. Study of action of surface-active additives in cutting fluid in the cutting of metal, and of the part

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played by strain hardening. Metal used in study: annealed aluminum. Numerical data on relation between concentration of surface-active substance (stearic acid, palmitic acid) in cutting fluid and degree of strain hardening, and on variation of cutting work as a function of the depth of hole drilled, with and without surface-active additives. Nature of effect of strain hardening in drilling with inactive and active cutting fluids. (Order No. 2405, Price $1.75)

On the Importance of Activated Liquid Lubricants-Coolants in the Deep Drawing of Metals, by S. Ya. Veiler & L. A. Shreiner; "Zhurnal Tekhnicheskoi Fiziki," Vol. 19, No. 1, 1949, pp. 84-87; 2 figs., 2 tables, 1,800 words. New method for evaluating the lubricating value of surface-active lubricating-cooling liquids, as used in deep drawing metals. Factors contributing to lowering of drawing force, with use of surface-active lubricants. Results of study and conclusion. (Order No. 2449, Price $3.35)

Effect of Nature of Metal upon Easing the Cutting Process by Adsorption, by G. I. Epifanov, P. A. Rebinder & L. A. Shreiner; "Doklady Akademii Nauk SSSR," Vol. 64, No. 5, 1949, pp. 879-880; 1 table, 1,050 words. Influence of propensity of metals to strain hardening upon softening effect of surface-active media (adsorption) in plastic deformation including cutting. Experimental arrangement and procedure. Metals studied: (1) aluminum, copper, (2) zinc, tin, cadmium, and (3) bronze, cast iron. Surface-active agents used in this study: heptanol, cetyl alcohol, caprylic and palmitic acids. Numerical data on cutting work, layer thickness removed, and drill torque for aluminum, zinc, and bronze. Conclusions as to nature of effect of cutting fluid with surface-active additives. (Order No. 2454, Price $1.90)

Phosphate Coating as an Aid in the Shaping of Steel, by A. Durer, "Archiv Eisenhuttenwesen," Vol. 20, Nos. 9 & 10, 1949, pp. 305-312; 9,500 words. Up-to-date review of subject, including a great deal of hitherto unpublished data. Technological significance of phosphate coating in non-cutting shaping operations. Reduction of frictional forces and wear. Resulting advantages. Possible use of low-priced lubricants. Constitution of phosphate coatings, their chemistry and physical characteristics. Behavior of phosphate coatings in shaping and exact nature of their action. Interaction between phosphate coating and lubricant, wettability characteristics, reaction with soap solutions. Application of phosphating in such shaping processes as wire drawing, and specific requirements to be met. How to test phosphate coatings for their suitability in shaping operations. Method for measuring the degree of coverage. (Order No. 2557, Price $16.65)

Patent Abstracts

(Compiled by Ann Burchick, Aluminum Co. of America.)

Mineral Oil Composition Containing an Improved Hydrocarbon-Phosphorus Sulfide Reaction Product, Patent No. 2,712,528 (M. W. Hill & R. H. Jones, assignors to Esso Research & Engineering Co.) A mineral oil containing in the range of about 0.001 to 20% of a product obtained by reacting about 1 molecular proportion of a phosphorus sulfide with 2 to 5 molecular proportions of a hydrocarbon material and further reacting the acidic product thus formed with 0.1% to 50% of its weight of a hydrocarbon containing at least one olefinic double bond.

Treatment of Alkaline Earth Metal Petroleum Sulfonates, Patent No. 2,713,034 (E. W. Clarke, W. Schreiber & P. D. Kneeland, assignors to The Atlantic Refining Co.) A method for producing purified oil solutions of barium sulfonates which comprises neutralizing a Mid-Continent crude distillate boiling within the lubricating oil range that has been treated with concentrated sulfuric acid with a barium compound and thereafter treating the resulting oil solution of barium sulfonates, resins, and high and low viscosity index hydrocarbon oil components with an aqueous isopropyl alcohol solution containing between 20 and 30 per cent water in a multi-stage extraction unit, utilizing between 2 and 3 volumes of aqueous isopropyl alcohol for each volume of oil solution, and separately recovering an extract layer composed primarily of the aqueous isopropyl alcohol solution, resins, and the low viscosity index hydrocarbon oil components and a raffinate layer composed primarily of the barium sulfonates and the high viscosity index hydrocarbon oil components.

Treatment of Alkaline Earth Metal Petroleum Sulfonates, Patent No. 2,713,035 (E. W. Clarke, assignor to The Atlantic Refining Co.) A method for producing purified oil solutions of barium sulfonates which comprises neutralizing with a barium compound a Mid-Continent crude distillate boiling within the lubricating oil range that has been treated with concentrated sulfuric acid and thereafter treating the resulting oil solution of barium sulfonates, resins, and high and low viscosity index hydrocarbon oil components with an aqueous methyl ethyl ketone solution containing between 0.5 and 7.0 per cent water in at least two extraction zones, utilizing between 2 and 3 volumes of aqueous methyl ethyl ketone for each volume of soil solution and separately recovering an extract layer composed

primarily of the aqueous methyl ethyl ketone solution, resins, and the low viscosity index hydrocarbon oil components, and a raffinate layer composed primarily of the barium sulfonates and the high viscosity index hydrocarbon oil components.

Method of Making Alumina Containing Catalysts, Patent No. 2,713,037 (C. N. Kimberlin, Jr., assignor to Esso Research & Engineering Co.) A process for preparing silica-alumina catalyst adapted for conversion of hydrocarbon oils, which comprises providing an anhydrous solution of an aluminum alcoholate, effecting intimate admixing of the aluminum alcoholate solution and silica hydrosol to cause intimate coprecipitation of silica and alumina, hydrolyzing the aluminum alcoholate by and reacting the aluminum alcoholate with the water in the silica hydrosol to form a hydrous silica-alumina composite and forming a water slurry of the resulting hydrous silica-alumina composite, and recovering and drying the silica-alumina composite to produce a catalyst.

Basic Phenates to Inhibit Silver Corrosion in Thiophosphate-Containing Lubricating Oils, Patent No. 2,713,557 (W. Lowe, assignor to California Research Corp.) A lubricating oil composition comprising a major proportion of an oil of lubricating viscosity having incorporated therein a small amount, sufficient to inhibit oxidation, of a metal salt of a mixed diester of dithiophosphoric acid, wherein one ester group is an alkyl radical having from 1 to 4 carbon atoms, and another ester group is an alkyl radical having from 6 to 18 carbon atoms, and said metal being selected from the group of zinc and calcium, and, in addition, a small amount, sufficient to inhibit the corrosion to silver caused by said metal salt of dithiophosphoric acid, of a "basic" sulfurized metal salt of an alkyl phenol having a metal selected from the group consisting of calcium and barium, wherein the metal of said phenol is present in an amount at least 10% in excess of that required to form a neutral phenate.

Lubricating Compositions, Patent No. 2,713,558 (H. E. Schmitz, assignor to Shell Development Co.) A lubricating composition comprising a major amount of a mineral lubricating oil and from about 0.1% to about 10% of an oil soluble divalent selenium dihydrocarbyl dithiocarbamate.

Process for Breaking Petroleum Emulsions, Patent No. 2,713,559 (A. H. Smith, assignor to Petrolite Corp.) A process for breaking petroleum emulsions of the water-in-oil type characterized by subjecting the emulsion to the action of a demulsifier including hydrophile synthetic products; said hydrophile synthetic products being obtained by reaction between (A) a

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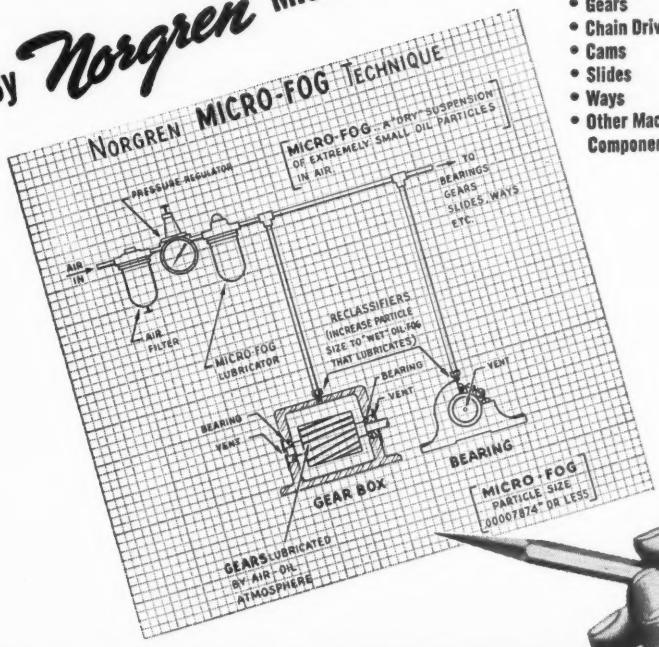

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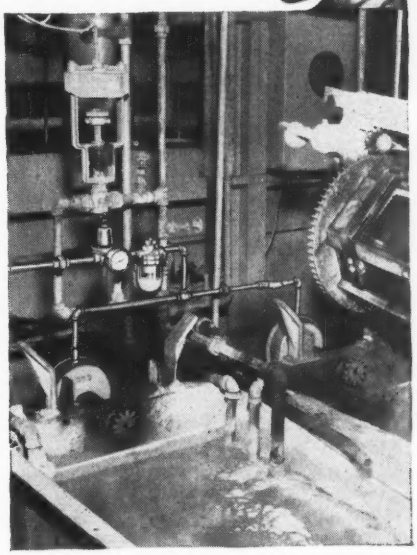

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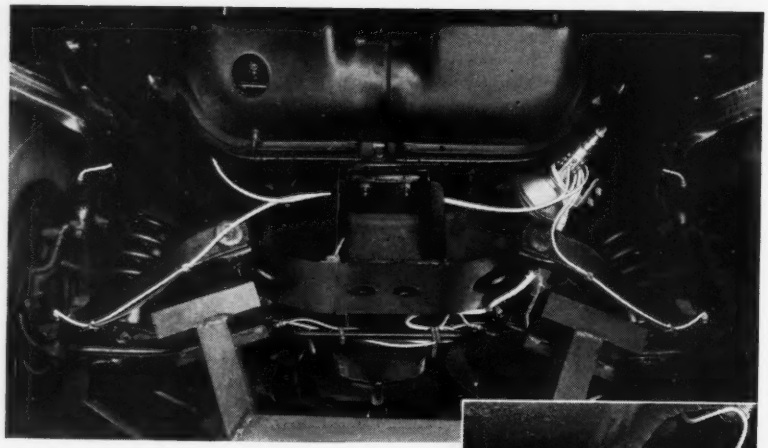

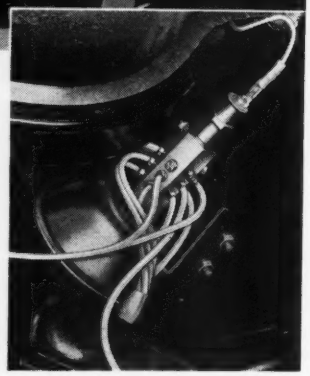

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polycarboxy acid, and (B) a highly oxypropylated substituted ring compound.

Preparation of Lubricating Grease, Patent No. 2,714,091 (I. E. Puddington & A. F. Siranni, assignors to National Research Council.) A process for the preparation of lubricating grease comprising adding to a mineral lubricating oil 5-25 parts by weight of a solid, hydrophilic, finely divided, low bulk density, absorbent material per 100 parts of the lubricating oil and a drying oil in the proportion of 10-100% by weight of the absorbent material, and heating the mixture for 2-3 hours at 100-150 C.

Lithium Base Grease Containing Group II Divalent Metal Alkyl Salicylate, such as Zinc Alkyl Salicylate, as Copper Corrosion Inhibitor, Patent No. 2,714,092 (C. H. Culnane & J. P. Dilworth, assignors to The Texas Co.) A lubricating grease composition comprising as the essential constituents an oleaginous liquid lubricating base of which at least the major proportion is a liquid aliphatic dicarboxylic acid ester within the lubricating viscosity range, about 10-30% by weight of a lithium soap of a saturated soap-forming fatty material, said grease normally being corrosive to copper, and from 0.25 to 5% by weight based on said composition of an oil-soluble metal alkyl salicylate.

Lubricating Oil Additives, Patent No. 2,714,579 (D. T. Rogers & J. P. McDermott, assignors to Esso Research & Engineering Co.) A composition comprising a major proportion of an oily vehicle selected from the group consisting of mineral oils, natural fatty oils and synthetic ester oils and containing 0.001 to 5% by weight, based on the total composition, of the reaction product of an arylsilanol in which at least two silicon bonds are occupied by aryl groups, the remainder of the silicon bonds being occupied by hydroxy groups and a phosphorus sulfide reacted to substantial completion at a temperature within the range of 150 to 250 C.

Lubricating Oil Composition, Patent No. 2,715,106 (E. W. Brennan & H. G. Raybould, Jr., assignors to The Pure Oil Co.) A lubricating composition comprising a mineral oil base having admixed therein minor proportions of a sulfurized-phosphorized terpene alcohol in an amount sufficient to impart anti-wear characteristics to said mineral oil and an oil soluble alkali metal organic sulfonate in an amount sufficient to enhance the effectiveness of said alcohol as an anti-wear agent.

Lubricating Compositions, Patent No. 2,715,107 (S. K. Talley, F. M. Fowkes & A. G. Cattaneo, assignors to Shell Development Co.) A lubricating composition comprising a major amount of a low viscosity oil having a Saybolt Universal viscosity at 210 F. not in

excess of 45 seconds and between about 0.01% and about 5% by weight, of a perfluoro-organic compound selected from the group consisting of perfluoro-organic acids, and amides thereof said compound containing between 2 and 14 carbon atoms per molecule.

Lubricating Compositions, Patent No. 2,715,108 (C. E. Francis, assignor to Shell Development Co.) An improved lubricant consisting essentially of a major amount of a mineral lubricating oil and minor amounts, sufficient to inhibit oxidation and corrosion of (a) an oil-soluble organic compound selected from the group consisting of oil-soluble hydrocarbyl-substituted aliphatic polycarboxylic acids, their monoesters and monoamides, (b) an oil-soluble phenolic compound, and a minor amount of about 0.01%, which amount is sufficient to effect complete demulsification, of (c) organic acidic compound selected from the group consisting of benzoic acid, salicylic acid, anthranilic acid, cinnamic acid and toluic acid.

Lubricating Oil Composition Containing Phosphorus Sulfide Hydrocarbon Reaction Product, Patent No. 2,715,612 (L. E. Beare, assignor to Sinclair Refining Co.) A steam-treated, clear, oil compatible, unneutralized reaction product of a mineral oil bright stock and about 7 to 17 per cent phosphorus pentasulfide at about 400 to 500 F., from which insolubles have been separated at a temperature of about 150-250 F. prior to steam-treatment.

Adhesive Petroleum Lubricant, Patent No. 2,716,085 (G. W. Ayers & W. A. Krewer, assignors to The Pure Oil Co.) A lubricating composition characterized by its adhesiveness to metal surfaces, comprising a major portion of a residuum from the distillation of a petroleum oil and a small amount of unctuous, stringy, non-crystalline wax tailings having an asphaltene content of not above 4 per cent by weight and a petroleum resin content of at least about 30 per cent by weight, a wax content of under 2 per cent by weight, and a sulfur content of about 2.4 per cent by weight.

Method of Filtering Dispersions of Metal Oxides & Hydroxides in Lubricating Oils, Patent No. 2,716,087 (R. L.Woodruff, P. K. Mulvany & J. O. Clayton, assignors to California Research Corp.) In the process of preparing liquid lubricating oil compositions comprising forming an admixture of a lubricating oil, a dihydric alcohol, a dispersant, an inorganic substance selected from the group consisting of polyvalent metal oxides and hydroxides, removing dihydric alcohol, and filtering the remaining admixture, the improvement which comprises blending into said admixture, prior to the filtration step, a filtering agent in an amount such that the mol ratio of said filtering agent to said inorganic substance has a value from about 0.1 to about 4.0, wherein said filtering agent is selected from the group consisting of lactic acid, glycolic acid, and the calcium salts of these acids, said lubricating oil composition being substantially free of acid from said filtering agent.

Lubricating Oil Composition, Patent No. 2,716,088 (L. A. Mikeska & C. A. Cohen, assignors to Esso Research & Engineering Co.) An improved lubricating composition which comprises a major proportion of a mineral lubricating oil and a minor proportion, sufficient to improve the detergency characteristics of said lubricating oil of a naphthenic non-aromatic calcium sulfonate of a white oil olefin, said white oil olefin having a molecular weight in the range of 450 to 600 and being derived from a naphthenic, non-aromatic white oil by chlorination with not more than about 0.5 mol of chlorine per mol of hydrocarbon at an elevated temperature below 100 C., followed by dehydrochlorination.

Motor Oil Inhibitor, Patent No. 2,716,089 (E. B. Cyphers & L. E. Moody, assignors to Esso Research & Engineering Co.) A composition comprising a mineral lubricating oil and a minor amount, sufficient to suppress coking of said oil, of an antimony salt of a dihydrocarbon dithiocarbamic acid, each of the hydrocarbon portions of said acid having in the range of 1 to 20 carbon atoms.

Plasticizing Agent for Mineral Oil Solutions, Patent No. 2,716,090 (N. V. Hakala & J. E. J. Kane, assignors to Esso Research & Engineering Co.) The method of preparing a mineral oil solution of a metal salt of a phenol sulfide which comprises reacting a phenol sulfide with a basic acting metal compound in the presence of a mineral lubricating oil containing a plasticizing amount of an alkylated phenol containing at least two alkyl groups of branched chain structure, each of which contains from 5 to 16 carbon atoms.

Rust Preventive Composition, Patent No. 2,716,611 (C. E. Paxton, assignor to Esso Research & Engineering Co.) A rust inhibiting composition consisting essentially of a major proportion of mineral base solvent oil, about 2 to 8% by weight based on the total composition of micro-crystalline wax of melting point between 140 and 190 F. and penetration below 40 mm./10 at 77 F., ASTM, as a primary film forming agent, and 0.2 to 3% of a long chain fatty acid partial ester of polyhydric alcohol as a surface active and synergistic rust inhibiting agent, said fatty acid portion of the partial ester containing from about 12 to 22 carbon atoms and said polyhydric alcohol portion is selected from the group consisting of sorbitan, mannitan and pentaerythritol.

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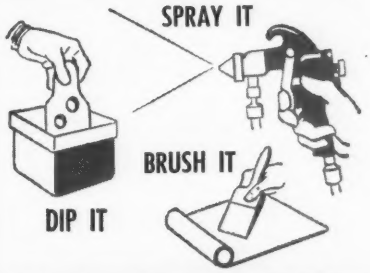

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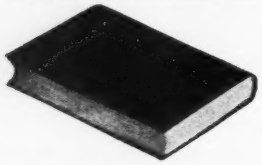

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Transparent Rust Preventive Cutting Oil Composition, Patent No. 2,716,634 (J. F. Black & J. D. Oathout, assignors to Esso Research & Engineering Co.) A water soluble composition suitable for use in aqueous cutting oils and rust preventives consisting essentially of a mixture of one part by weight of an oil soluble alkali metal petroleum sulfonate, in the range of 0.5 to 2.0 parts by weight of a mineral lubricant base stock, in the range of 0.02 to 0.4 part by weight of a rust inhibitor selected from the group consisting of alkali metal nitrites and alkali metal chromates, and in the range of 0.02 to 0.4 part by weight of an acidic material selected from the group consisting of alkali metal dihydrogen phosphates and long chain aliphatic monocarboxylic acids having about 12-22 carbon atoms in the aliphatic chain.

Tall Oil Pitch-Phosphorus Sulfide Reaction Product & Metallic Salts as Dispersants for Lubricating Oils, Patent No. 2,717,241 (E. O. Hook & L. C. Beegle, assignors to American Cyanamid Co.) A lubricating composition comprising a hydrocarbon lubricating oil having dissolved therein a detergent composition operative to assist in preventing the deposition of hard deposits due to sludge formation in the oil, said detergent composition comprising as its essential ingredient a neutralized reaction product resulting from chemically reacting a phosphorus sulfide with a mixture comprising from about 1% to 75% by weight of a member of the group consisting of tall oil pitch, partially saponified tall oil pitch, and completely saponified tall oil pitch and at least 25% by weight of a member of the group consisting of an unsaturated ester wax, a partially saponified unsaturated ester wax and a completely saponified unsaturated ester wax, and neutralizing the reaction product with a suitable reactive metal compound.

Polyoxyalkylene Lubricant Composition, Patent No. 2,717,242 (E. G. Foehr, assignor to California Research Corp.) A lubricant composition comprising a dialkyl poly-1, 2-propylene glycol diether having a molecular weight of from about 400 to 800 and wherein the alkyl end groups contain from 1 to 8 carbon atoms, together with an amount of from about one-fourth to about fourfold, in terms of the volume of said ether, of a member of the group consisting of tetraalkyl silicate and hexaalkoxy disiloxane wherein said alkyl groups contain from 5 to 8 carbon atoms each and have a branched-chain structure.

Sulfonation of Mineral Oil, Patent No. 2,717,265 (H. L. Johnson, assignor to Sun Oil Co.) In a process for preparation by sulfonation, of mahogany sulfonic acids from a mineral oil having at least 1.2 aromatic rings per molecule in the aromatic portion thereof, the improvement which comprises: prior to said sulfonation, contacting said mineral oil in liquid phase with hydrogen under hydrogenation conditions to effect a decrease of at least 0.005 in the refractive index N_d^{20} of the aromatic portion of the oil, and to effect a decrease of not more than 15 percent in the aromatic content of the oil.

Preparation of Organosilicon Compounds, Patent No. 2,717,900 (E.P. Plueddemann & D. B. Hatcher, assignors, by mesne assignments, to Allied Chemical & Dye Corp.) An oil formed by reacting under heat a mixture comprising (A) a hydroxyl-containing polyhydric alcohol partial ester, of a 2 to 18 carbon atom fatty acid, containing (1) 0.9 to 2.1 free alcoholic hydroxyl groups per molecule and (2) at least 9 residues of said fatty acid for every 10 of said polyhydric alcohol with (3) at least 90 per cent of its esterified hydroxyl groups being esterified with said fatty acid and (B) a reactive group containing organosilicon substance, selected from the class consisting of hydrocarbon-substituted chlorosilanes and the hydrocarbon-substituted alkoxysilanes and their partial hydrolysis products containing (1) an average of from one-third to three reactive groups per silicon atom and (2) an average of from 0.8 to 1.25 of said hydrocarbon substituent groups, each containing at least two carbon atoms, attached by carbon-silicon bonds to each silicon atom, and (3) in which at least 75 percent of its silicon atoms have but a single such hydrocarbon substituent; said reactants (A) and (B) being present in said mixture in proportions to provide from 1 to 1.25 equivalents of said reactive groups per equivalent of hydroxyl in said partial ester.

Lubricants Containing Ethers with Multiple Sulfur Linkages, Patent No. 2,718,499 (G. E. Barker & G. E. Alter, Jr., assignors to Elgin National Watch Co.) A lubricant consisting of 99.5 parts of amylthio-benzylthio-dipropyl sulfides, 0.2 part of p-tertiary butyl catechol, and 0.3 part of dodecylpiperidine stearate; and characterized in having a pour point of about minus 90 degrees F., no cloud point down to about minus 90 degrees F., and being non-spreading on steel and jewel surfaces.

Rust Inhibited Composition, Patent No. 2,718,500 (H. W. Rudel & Marion Gargisa, assignors to Esso Research & Engineering Co.) A rust inhibited composition comprising a major proportion of a hydrocarbon, 0.00025 to 0.5% by weight, based on the total composition, of an oil soluble acid ester of a phosphorus acid containing at least one hydrocarbon radical of 3-20 carbon atoms and 0.00025 to 0.5% of an alkyl mercapto acetic acid having about 8-20 carbon atoms in the alkyl group, the total amount of said ester and alkyl mercapto acetic acid being sufficient substantially to inhibit rusting by said hydrocarbon.

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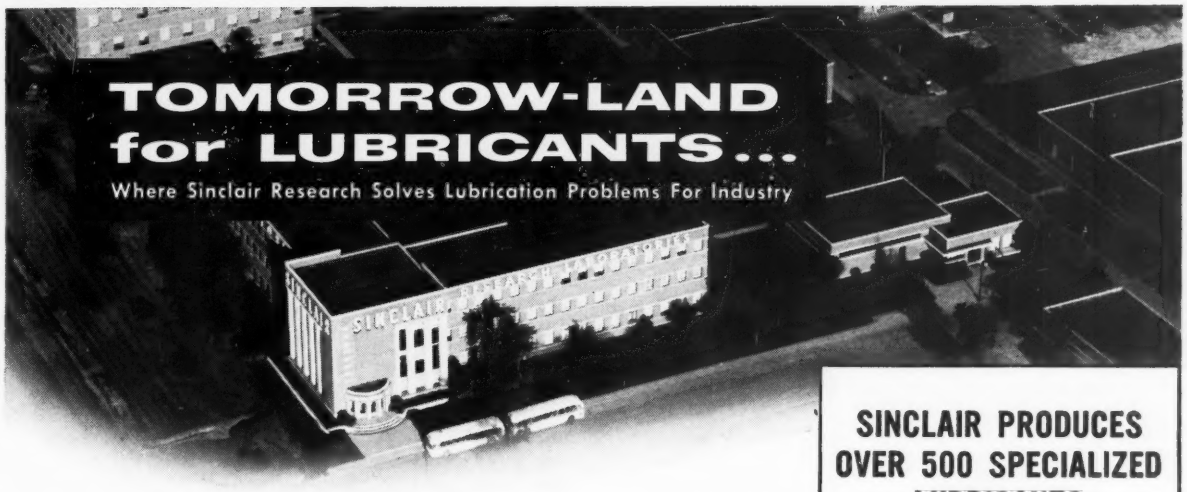
Lubricant Compositions, Patent No. 2,718,502 (E. S. Francis & R. R. Shoemaker, assignors to Gulf Research & Development Co.) A lubricant composition consisting essentially of about 0.5 to 10 per cent by weight of an ester formed by the reaction of glycerol with mixed acids prepared by the air oxidation of petrolatum, about 0.25 to 5 per cent by weight of a phosphatide, and a petroleum hydrocarbon oil having a viscosity at 210 F. of about 65 to 90 Saybolt Universal seconds.

Anticorrosion Agents Consisting of the Monamides of Dimerized Fatty Acids, Patent No. 2,718,503 (A. G. Rocchini, assignor to Gulf Research & Development Co.) A mineral oil composition comprising a major amount of a mineral oil and a minor amount, sufficient to impart corrosion inhibiting properties to the composition, of a monoamide of an amine having from 1 to 2 hydrocarbon N-substituents at least one of which contains at least 6 carbon atoms and a dimer of an unsaturated fatty acid having from 6 to 22 carbon atoms and containing from 2 to 3 ethylene linkages per molecule.

Compounded Mineral Lubricant, Patent No. 2,719,121 (R. P. Nejak & E. B. Cyphers, assignors to Esso Research & Engineering Co.) A lubricant composition consisting essentially of a mineral oil and in the range of about 0.05 to 5.0% by weight of a dialkyl phenothiazine, the alkyl groups each having in the range of 4 to 16 carbon atoms, and in the range of about 0.1 to 5.0% by weight of a compound selected from the class consisting of zinc naphthenates and magnesium naphthenates.

Complex Alkali Metal Soap-Alkaline Earth Metal Salt Thickened Grease Composition, Patent No. 2,719,122 (A. J. Morway, assignor to Esso Research & Engineering Co.) A lubricating grease composition comprising a major proportion of grease-forming lubricating oil and a minor grease-thickening proportion of a complex thickener, said thickener consisting essentially of alkali metal soaps of saturated fatty acids of the C_{12} to C_{22} range and alkaline earth metal salt of monobasic carboxylic acids of the C_1 to C_6 range in substantially equimolar proportions.

Grease Compositions Containing Oxonated Acid Soaps, Patent No. 2,719,124 (L. A. Mikeska & A. J. Morway, assignors to Esso Research & Engineering Co.) A lubricating grease composition which consists essentially of a lubricating oil base stock thickened to a grease consistency with a metal soap of the hydrogenated reaction product of a material selected from the group consisting of oleic acid and the esters of oleic acid with carbon monoxide and hydrogen in the presence of a cobalt catalyst at temperatures of from 150 to 450 F. and pressures of from 1000 to 5000 pounds per square inch.



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(Book Reviews, from p. 122)
service such as steam turbines, steam cylinders, internal combustion engines, power plant auxiliaries, electric motors, and others.

Because of its straight-forward exposition, the book could be of considerable value in a lubrication training course where its emphasis on practical aspects would also help. A rather detailed table of contents clearly traces the book's development and is an aid for reference use. Lubricant uses which are cited are specific rather than general.

This reviewer feels the book's value to be primarily in the machine component section, as the discussions on general subjects such as internal combustion engines are too brief for adequate coverage. References shown after each chapter are mostly to industrial publications and are not tied in directly with the text, thereby giving wider practical subject coverage. Many illustrations and tables are included. As indicated by its title, the book stresses the art of lubrication practice and should, therefore, have wide applicability among those who are concerned with the day to day use of these materials.

ASTM Viscosity Index Calculated From Kinematic Viscosity, Special Technical Publication No. 168; American Society for Testing Materials, Philadelphia, Pa., 1955; 832 pages, price $8.00 (to ASTM members $6.00).

The tables in this publication permit direct reading of the Viscosity Index of a petroleum product or lubricant, if its kinematic viscosities at 100 F. and 210 F. are known. Use of these tables eliminates the calculation required for determining V.I., an empirical number that indicates the effect of change of temperature on the viscosity of an oil. A low V.I. signifies relatively large change of viscosity with temperature.

The V.I. values listed in these tables were calculated by I.B.M. machines using the basic V.I. formula given in the Standard Method for Calculating V.I. (ASTM Designation: D567. The basic values of *L*, *H*, and *D* punched in I.B.M. cards during the preparation of Table I of Method D567 and Table III of Special Technical Publication 43A (Basic Values for Calculating Viscosity Index from Kinematic Viscosities) were used. These values were extended to the fifth decimal place to obtain greater accuracy. The printed tables were reproduced directly from the tabulated copy prepared by the I.B.M. machine to eliminate transcription and typesetting errors.

These tables were prepared to meet the need and demand for convenient reference tables for obtaining calculated V.I. quickly and accurately; they were prepared by Section A on Viscosity Methods for Newtonian Liquids, of Research Division VII on Flow Properties, of ASTM Committee D-2 on Petroleum Products and Lubricants.

(Current Literature, from p. 125)
tem. While the Index is primarily intended to establish a comprehensive system by which ASTE Data Sheets and related information may be filed (it is not a listing of available Data Sheets), it serves a dual purpose. Of equal importance to its principal function, is the fact that it can also be used to number and file the mass of engineering information and data that constantly accumulates. Articles, tables, or data can be numbered and filed for easy reference. Although the numbering is different, the Index works in the same manner as the Decimal System used by libraries the world over. Every item or class of item is given a specific seven-figure

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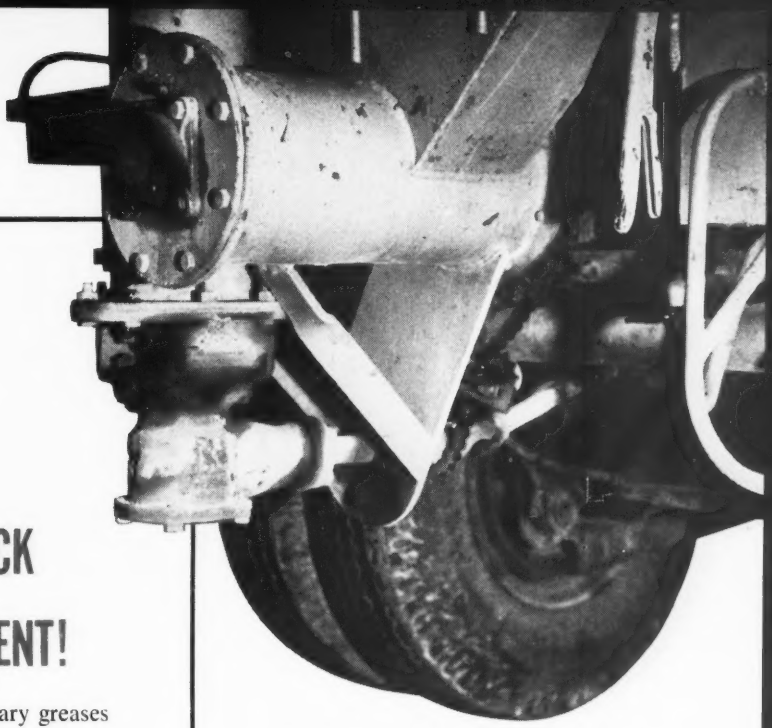

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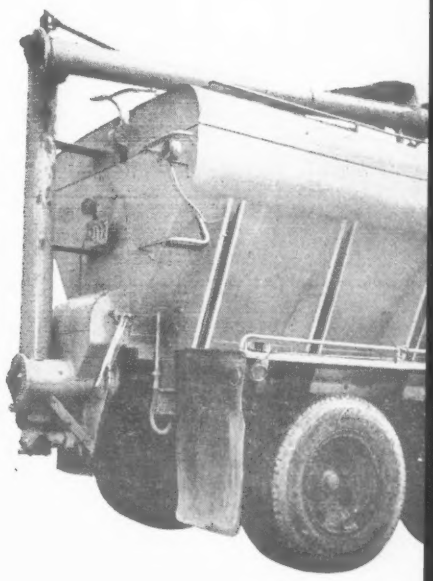

Texas fleet truck operator says Bentone grease cuts lubrication costs in half.

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number. The first two numbers represent the group; this is followed by a dash and five more numbers which break down systematically into sub-classifications. Under each group there are 90,000 classified and interrelated numbers available. The ASTE Index comes in two parts: (1) the Numerical Listing, which is abridged but shows the basic structure and logic of the ASTE Edition of the U. S. Standard Commodity Classification, and (2) the Alphabetical Listing, which is merely a cross reference index of the same numerical material expanded for the specialized use of the tool engineer. (Direct inquiries to: National Standards Committee, ASTE, 10700 Puritan Ave., Detroit 38, Mich.)

Wheel Bearing Grease Tester. Bulletin 718 describes the redesigned Wheel Bearing Grease Tester, an apparatus for determining the leakage tendencies of wheel bearing greases according to the ASTM method. In addition to the ASTM test, the bulletin discusses tests for changes in grease characteristics under simulated service conditions. Also described are such features of the apparatus as forced air convection and a hydraulic thermostat which holds the spindle temperature within ±2.5 F. at the test temperature of 220 F. (Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.)

1956 Service Data. A reference of 1956 passenger car service locations and lubricant recommendations is immediately obtainable in "Service Data," an annual publication of The Chek-Chart Corp. Appearing this year in a specially designed wall chart form, all service location variations have been incorporated into one master diagram. Complete motor oil and gear lubricant recommendations are provided in a tabular listing, and a new section under the heading "On the Driveway" shows basic methods of applying the information given. (The Chek-Chart Corp., LE-12/2, 33 East Congress Parkway, Chicago 5, Illinois, price 50 cents.)

Review of Laboratory Apparatus. "Lanco Apparatus Review No. 6" describes and illustrates 1955's best sellers in the line of laboratory apparatus. A separate 4-page section introduces Harleco volumetric solution concentrates. Equipment described includes atom models, Ohaus balances, Reyers-Rapid Balances, glass beads, stainless steel beakers and labware, Ultramax burettes and separatory funnels, glass blowing burners, carts, polyethylene centrifuge tubes, jumbo hosecock clamps, lattice support rods, portable bath coolers, electronic relays, Electrothermal tapes, Flash-Evaporators, hot plates, hot plate magnetic stirrers, illuminated magnifier, heating mantles, multiple plug-in controls, particle size apparatus, marking pens, slide rule psychrometers, pressure and vacuum pumps, cylinder drying racks, instrument shields, polyethylene sink traps, folding stirrer paddles, stirrers, stools, and safety cylinder supports. (Arthur S.

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"Trona" Lithium Hydroxide. An informational bulletin on "Trona" lithium hydroxide has been issued by the American Potash & Chemical Corp. for use in such industries as petroleum, storage battery manufacturing, lithium salt production, industrial plants needing an absorbent for gases in their production processes, and other applications. The pamphlet provides information on potential uses, results of laboratory tests on lithium-base greases and other material. (American Potash & Chem. Corp., LE-12/2, 3030 W. 6th St., Los Angeles, Calif.)

Vane-Type Hydraulic Motors. Bulletin DM321 describes Dudco MF-100 series vane-type hydraulic motors. The balanced dual-vane fluid motors are constant displacement type whose speed varies directly with the quantity of fluid supplied, and with a torque varying directly with the pressure. Completely illustrated, the bulletin contains data on selection, mounting, and connections. (Kalamazoo Div., New York Air Brake Co., LE-12/2, Kalamazoo, Mich.)

High-Pressure Automatic Lubricators. Bulletin 3A describes a line of lubricators applicable to a wide range of machines, such as printing presses, machine tools, packaging, labeling, and bottling machines. The bulletin treats details of the adjustable time cycling mechanism used to deliver metered quantities of oil with the automatic lubricators. Reservoirs, oil filters, and single-feed line distribution systems are also described. (Bijur Lubricating Corp., LE-12/2, 151 W. Passaic St., Rochelle Park, N. J.)

Fire-Resistant Hydraulic Fluid. A new, 8-page bulletin describing Houghto-Safe fire-resistant hydraulic fluid has been released that contains factual information on installation and maintenance of this fluid where potential fire hazards exist. Technical data is given on installation as relating to packings, pumps, strainers, filters, and other parts of the system. The importance of pumpability at low temperature and storage stability are also covered. Typical uses of Houghto-Safe are outlined in this folder, which also summarizes the advantages of the product and includes testimonials from users. (E. F. Houghton & Co., LE-12/2, 303 W. Lehigh Ave., Phila. 33, Pa.)

"Trouble-Shooting Chart for Hydraulic Systems," is the subject of a new wall chart offered by the Sun Oil Co. to help operators and maintenance men spot and cure common troubles. (Sun Oil Co., LE-12/2, 1608 Walnut St., Phila. 3, Pa.)

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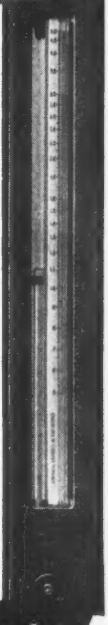

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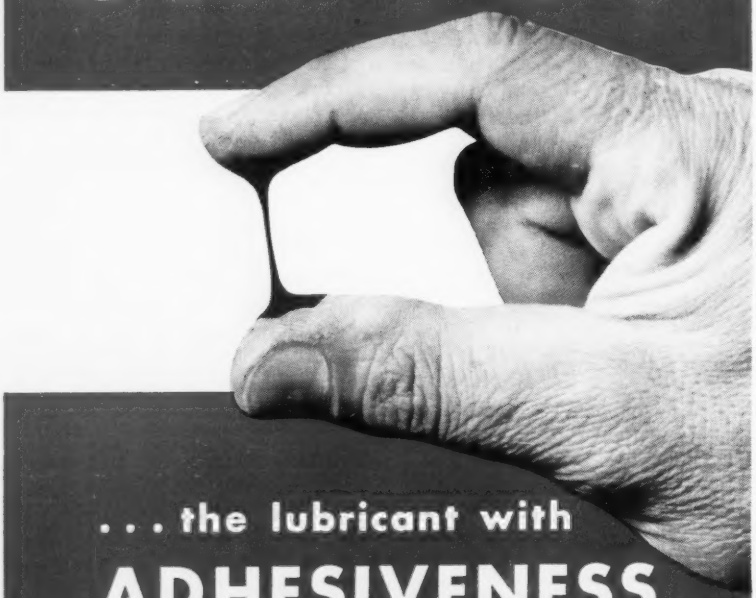

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(Lube Lines, from p. 89)
oil leaking between the piston and cylinder. Use of this type of compressor in refrigeration service would eliminate the need for an oil separator; in the chemical industry it is said to assure oil-free compressed air, carbon dioxide, oxygen, and other gases.

SPRAY LUBRICATION. Spray lubrication of enclosed gears in steel mill service is one of the feature developments reported by "Iron & Steel Engineer" (Jan. '56) for the iron and steel industry during 1955. A self-contained panel is mounted on the gear housing in such a manner as to insure delivery of the lubricant via spray valves directly to the pressure side of the gear teeth. Using a central pumping unit for periodic delivery of lubricant, it can be presumed that this method of gear lubrication should be economical of lubricant, conducive to cleanliness, and adapted to lower viscosity gear lubricants of the additive-type.

ASME LUBRICATION DIVISION. The Council of the American Society of Mechanical Engineers has approved the application of the ASME "Lubrication Activity" for Professional Division status. This is the result of the realization of the ASME Petroleum Division in 1949 that lubrication cut across the activities of all the Professional Divisions. Immediately the "Lubrication Activity" became popular with all whose responsibilities included lubrication from the operating, maintenance, and research angles. The untiring efforts of A. C. Stutson of Socony Mobil Oil Company as chairman, and the cooperation of an active group of over 200 engineers, insured the success of the "Lubrication Activity." It is a credit to these people, many of them members of ASLE, that Division status is now a reality.

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(Men of Lubrication, from p. 91)
lubrication; and he was actively engaged in theoretical and experimental research supported by the Milton Fund and by special grants from the Research Committee on Lubrication of the American

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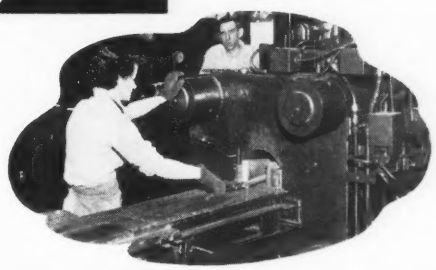

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Society of Mechanical Engineers."

Norton made a very significant contribution to the subject of lubrication by developing its theory into a connected whole suitable for presentation in the class room. His notes, which had been evolved in the course of about eight years of teaching the subject, are the basis of his book, "Lubrication," which was published posthumously in 1942. These notes had been intended by him to be the basis of a book, and at the time of his death in 1940 the material was almost complete. The book was actually carried through publication by his assistant, Mr. James R. Muenger. It is an excellent treatment of the basic theory of lubrication, and as a textbook for a course of study in the subject probably the most satisfactory of all the works on the subject. Norton's work on fluid behavior under high pressures, including studies of high shear rates, is a very significant contribution to fundamental questions which are still far from completely answered. His paper on this work, "Flow Properties of Lubricants Under High Pressure," by Norton, Knott, and Muenger, appeared in the Transactions of the American Society of Mechanical Engineers for 1941, page 631.

Norton's inclination was toward the design or analytical rather than to the experimental side of engineering. It has been mentioned that he was greatly influenced by the new trends in engineering science during the twenties. To promote these interests, he was active in encouraging young men in these more advanced studies and in raising the standard of engineering instruction.

Norton's home life was quiet and cultured. One of his students has described him as a "gentleman," and a former colleague remarked that he was a "grand fellow." On all sides he seems to have inspired an unusual warmth of admiration. His principal outside interests were his church work and a great fondness for classical music. He was an accomplished pianist. Vacations were, for the most part, spent at his summer home on the Isle of Springs, Booth Bay Harbor, Maine, where he found congenial company with friends and colleagues.

In 1920 Norton received an honorary A.M. from Brown University. He was a Fellow of the American Academy of Arts and Sciences, and a Past President of the Massachusetts Chapter of the American Society of Heating and Ventilating Engineers.

ACKNOWLEDGEMENTS. The main sources consulted in the preparation of this article were: "Minute on the Life and Services of Arthur Edwin Norton," which appeared in the Harvard Gazette on February 7, 1942; and the Preface and Foreword to Norton's "Lubrication." The author is also indebted to Mr. Gardner Norton, and to Mr. Warren C. Norton, Norton's son and brother, respectively, for their help; and to several former colleagues and students.

(This is the eighth in a series of articles by F. R. Archibald, Analyst, of Arthur D. Little, Inc.)

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New Farval spray panel lubricates gearing automatically, efficiently, inexpensively

FARVAL—
Studies in Centralized Lubrication
No. 183

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Shown at right is a new Farval Spray Valve System developed for large-diameter wide-faced gears. Installed on a panel mounted on the gear housing are Dualine valves, spray valves and reversing valve. An automatic air-operated barrel pump supplies the lubricant.

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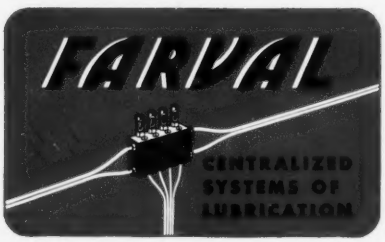

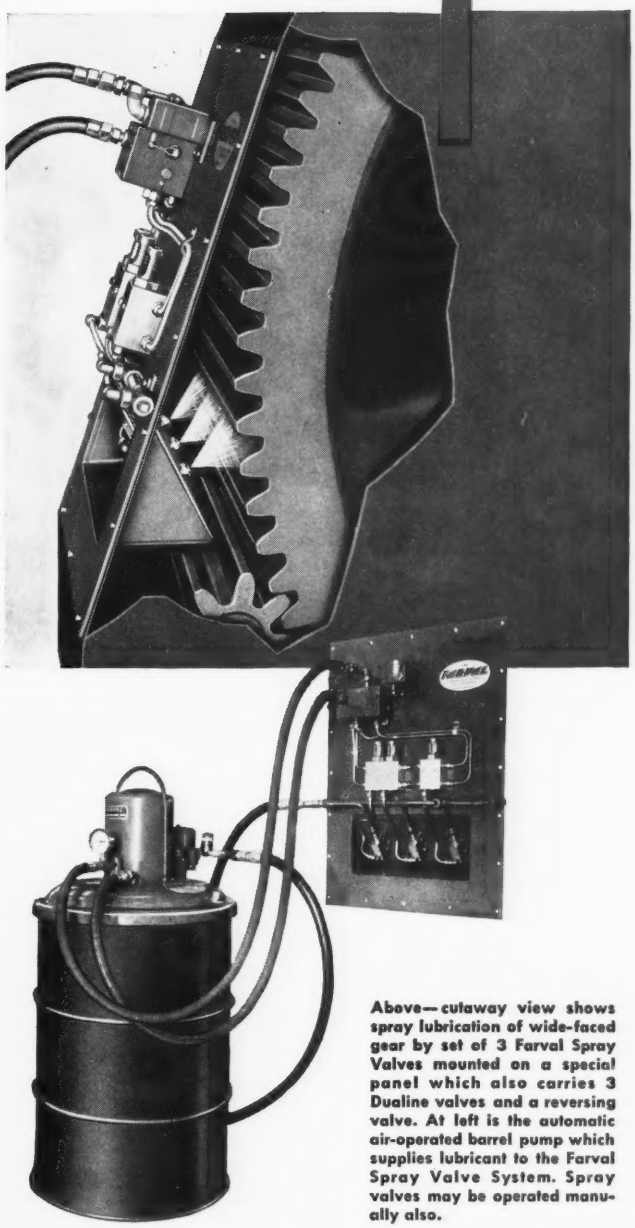

Above—cutaway view shows spray lubrication of wide-faced gear by set of 3 Farval Spray Valves mounted on a special panel which also carries 3 Dualine valves and a reversing valve. At left is the automatic air-operated barrel pump which supplies lubricant to the Farval Spray Valve System. Spray valves may be operated manually also.

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